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Analyses of Gaze in Music Tasks: Score Reading and Observations of Instrumental Performance

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Analyses of Gaze in Music Tasks: Score Reading and Observations of Instrumental Performance

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Dedication

For Gordon – I am forever grateful for your constant love and support.

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Abstract

Analyses of Gaze in Music Tasks: Score Reading and Observations of Instrumental Performance

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The optimal allocation of attention is a central feature of expert music teachers' capacity to create meaningful change in student performances. Experts consistently identify the most important components of relevant behavior, and then direct learners' attention in ways that bring about productive changes in thinking and motor control.

In this dissertation, the eye movements of music teachers with varied levels of experience and expertise were analyzed in two different contexts: music score-reading, and observation of human motor behavior in music and nonmusic settings. In one experiment, faculty, graduate-, and undergraduate-level conductors read excerpts from one familiar and one unfamiliar instrumental music score while listening to a metronome set to the tempo of the musical pulse in each piece and again while listening to audio recordings of the music. Expert score reading was characterized by frequent musically relevant (informative) fixations that were timed consistently ahead of the ongoing music. Experts also fixated more lines the music texture than did nonexperts, perhaps an indication of their internal perception of the entirety of the excerpts they read. Less experienced participants fixated many more irrelevant targets and often fixated behind the ongoing music in time. Less experienced participants also tended to follow individual lines in the score, especially in the unfamiliar excerpt, and this narrow visual focus may be an indication of limitations in their ability to hear or imagine all components of the music simultaneously.

In a second experiment, artist-faculty, graduate-, and undergraduate-level flute players observed six video recordings of individual performers playing flute, clarinet, and saxophone, and three recordings of individuals juggling, batting a baseball, and dancing ballet. Experts' mean fixation durations were substantially longer during the flute, clarinet, and saxophone videos than were the nonexperts'. Experts also devoted more fixation time to the embouchure in the music videos, perhaps noting the dynamics of the embouchure over time. Nonexperts also fixated the embouchures, but looked at other targets as well; their fixations tended to be shorter than the experts'.

The results of these two studies reveal expert music teachers' clarity and intentionality in directing attention to the most informative aspects of their environment, and demonstrate how fixation duration varies in relation to the task at hand. In the case of music score reading (i.e., viewing static images), experts tended to fixate for shorter durations than did nonexperts, and the scan paths of experts indicated attention to multiple voices in the music texture. In observations of human behavior, music performance behavior in particular, experts fixated for longer durations, focusing on the most important features of performers behavior as they developed over time.

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Chapter I: Introduction and Review of Literature

INTRODUCTION

Organisms moving through environments confront a vast array of stimuli, much of which informs the activation of behavior in attempts to optimize internal conditions and accomplish external goals. Complex nervous systems with extensive capacities to form and store memories allow for making informed predictions about the world that further guide action and decision making (e.g., Bubic, von Cramon, & Schubotz, 2010; Clark, 2013; Wills, Lavric, Croft, & Hodgson, 2007). The brains of human beings and other primates exemplify the processes involved in selectively attending to and prioritizing stimuli that are important for accomplishing momentary goals and ignoring those that are not. Because it is possible to actively *seek* information that is useful in the near term, the overt behavior of looking provides a window into thinking and decision making (Hayhoe, 2017; Land, 2006; Tatler, Hayhoe, Land, & Ballard, 2011; Yarbus, 1967, p. 190).

Behavior is motivated by a discrepancy between the current state of an organism and a desired goal state (e.g., Tomasello, Carpenter, Call, Behne, & Moll, 2005; Wasserman, 1993). Internal feelings like hunger, thirst, fear, and curiosity serve to motivate behavior to relieve disequilibrium (e.g., satisfy the hunger, thirst, or curiosity, escape the fear inducing stimulus) (Damasio, 2018; Tomasello et al., 2005; Wasserman, 1993).

Nearly all informal observations of human behavior provoke implicit inferences in the minds of observers about what actors are doing and why they are doing it, a process that is central to social cognition (e.g., Bandura, 1977, 1986, 2006; Rosenthal & Zimmerman, 2014). Observing the behavior of individuals as they attempt to affect the world around them, including the people in it, provides clues about proximal goals, the allocation of attention, and other aspects of thinking (Bargh & Chartrand, 1999; Nosek, Hawkins, & Frazier, 2011).

Rigorous systematic observation procedures often reveal constellations of overt behaviors that suggest relationships between apparent intentions and goal-directed actions, and such data can support even more elaborate inferences about human thinking, perceiving, and decision making (Bordens & Abbott, 2011; Hintze & Matthews, 2004; Suen & Ary, 2014). Measurements of physiological responses may further contribute to investigations of thinking, often revealing information about individuals' internal states that are not revealed in behavioral observations and self-report data (e.g., Coles, 1989; Ivonin, Chang, Diaz, Catala, Chen, & Rauterberg, 2015; Mauss, Cook, Cheng, & Gross, 2007). Yet, despite the informative potential of these types of procedures in contributing to what we understand about the people who inhabit the world around us, describing the underlying perceptual, emotional, and cognitive processes that lead to decisions and prompt actions, especially within complex and multifarious skills, remains a daunting challenge (Bargh & Morsella, 2008; Borko, Livingston, & Shavelson, 1990; Copeland, Birmingham, DeMeulle, D'Emidio-Caston, & Natal, 1994; Nisbett & Wilson, 1977; Hall & Smith, 2006).

Of course, one may simply ask individuals to explain their behavior after the fact, and their responses may indeed betray some aspects of thinking. So-called “think-aloud” protocols have also been a prominent feature in many domains of social science research (Boren & Ramey, 2000; Ericsson & Simon, 1984; Ericsson & Simon, 1998; Jääskeläinen, 2010; Fonteyn, Kuipers, & Grobe, 1993). But ample data illustrate that decisions and actions are driven at least in part by processes that operate below conscious awareness, and answers to queries about conscious intentions may not accurately reflect the actual thinking that leads to a given behavior or suite of behaviors (Bargh & Chartrand, 1999; Clarke, Mahon, Irvine, & Hunt, 2017; Donaldson & Grant-Vallone, 2002; Fazio & Olson, 2003; Nosek et al., 2011). The general untrustworthiness of think-aloud protocols and post hoc explanations is not a function of intentional deception on the part of the subject of study, but is a result of a more general inability to access fully the details of one’s own decision making (Guerin, Leugi, & Thain, 2018; Nisbett & Wilson, 1977; Potter & Hepburn, 2005).

An additional, and often untapped, source of information about human perception and cognition is the movement of the eyes. The human visual system functions to acquire information to guide motor control and decision making. Eye movements comprise an ongoing succession of alternating ballistic jumps from one position to another (called *saccades*) and momentary pauses that focus on various aspects of a visual scene (called *fixations*). The eyes are never entirely stationary, and even when fixating a given target in a scene, very small, very fast movements (called *microsaccades*) are nearly always present.

When and where the eyes move are indicators of cognitive attention (Buschman & Miller, 2010; Corbetta et al., 1998; Corbetta & Shulman, 2002; Kowler, Anderson, Dosher, & Blaser, 1995; Orquin & Mueller Loose, 2013; Yarbus, 1967), and numerous investigations have demonstrated the utility of recording eye movements as a way to better understand various aspects of thinking and behavior, including perception and motor control (Corbetta et al., 1998; Kowler et al., 1995; Orquin & Mueller Loose, 2013). It is now well documented, for example, that fixation duration is a general indicator of cognitive processing time, with longer fixations indicating greater cognitive demand (e.g., greater complexity or unfamiliarity of the stimulus) (Bigand, Lalitte, Lerdahl, Boucheix, Gérard, & Pozzo, 2010; Buswell, 1921; Goldberg, 1999; Goldberg & Schryver, 1995; Just & Carpenter, 1980; Rayner, Chace, Slattery, & Ashby, 2006).

EXPERTISE AND COMPREHENSION OF VISUALIZATIONS

The study of experts may serve not only to document *what* experts do, but also to provide a window into expert thinking that illuminates the *how* and *why* of expert behavior. Comparing the behavior of experts and novices in a given domain affords additional information as to how expertise develops over time and may reveal the critical features that characterize expertise (Berliner, 1986, 1988, 2001, 2004; Carter, Cushing, Sabers, Stein, & Berliner, 1988; Chi, 2006; Ericsson, 2008; Ericsson, Krampe, & Tesch-Römer, 1993; Madsen, Standley, Byo, & Cassidy, 1992).

Conducting research about expert thinking and behavior first requires a useful definition of the term expertise. What defines an expert? What constellation of indicators together form a criterion for labeling a practitioner an expert? One of the common characteristics of expertise in every domain is a deep knowledge of the relevant subject matter (Bilalić, 2018; Chase & Simon, 1973; Gobet, 2016; Gobet, Lane, Crocker, Cheng, Jones, Oliver, & Pine, 2001; Gobet & Simon, 1996). This deep knowledge includes an advantageous organization of the elements of memory, one that facilitates retrieval, application, and transfer of learned knowledge, skills, and dispositions. These interconnected knowledge structures facilitate pattern recognition and the rapid, timely access of useful information (Bilalić, 2018; Gobet, 2016).

Experts confronted with new situations quickly attend to the important elements of the environment and to patterns of stimuli that are germane to the accomplishment of goals. This pattern recognition, called *chunking* (Chase & Simon, 1973), quickly activates neural networks of previously stored memories that are related to new circumstances (also called *templates* by Gobet & Simon, 1996). Compared to novices, experts not only recognize important information in a new scene more quickly, but also perceive the scene fundamentally differently based on organized structures (including past experiences) stored in memory.

A number of investigations have explored the visual perceptions of experts in various domains, and their results have led to competing theories to explain the processes involved in visual perception. Ericsson and Kintsch (1995) proposed that the development of expertise extends capacity and speed of processing as a result of retrieval structures that allow for rapid encoding of information and ease of retrieval. Their theory of "long-term working memory" predicts that during skilled performance activities, such as chess, sports, music, and medical diagnoses, experts' fixations are shorter than novices'. Haider and Frensch (1999) proposed that expert perception is a product of information selectivity, as illustrated in a study in which participants were asked to look at a string of letters and numbers and determine whether the letters were in alphabetical order. Participants effectively ignored the numbers in the sequence, fixating only the letters. Haider and Frensch proposed an information-reduction hypothesis, which purports that experts learn to selectively attend to the most important information in their environments, ignore irrelevant stimuli, and fixate task-relevant targets longer than do novices.

After observing mammographers with different levels of experience to detect a mass on an image, Kundel, Nodine, Conant, & Weinstein (2007) proposed that the development of expertise changes perceptual processes in ways that extract more information from a given array of stimuli. Expert mammographers were quicker and more accurate than novices in assessing an entire image and locating the target mass. Kundel and colleagues' holistic theory explained that:

> "The rapid initial fixation of a true abnormality is evidence for a global perceptual process capable of analyzing the visual input of the entire retinal image and pinpointing the spatial location of an abnormality. It appears to be more highly developed in the most proficient observers, replacing the less efficient initial search-to-find strategies" (p. 396).

These theories are not mutually exclusive, of course, and studies of expert perceptual acuity demonstrate their overlap (see Gegenfurtner, Lehtinen, & Säljö, 2011 for a review). Depending on the task, experts may exhibit shorter fixation durations than do novices (e.g., Donovan & Litchfield, 2013; Kasarskis, Stehwien, Hickox, Aretz, & Wickens, 2001; Truitt, Clifton, Pollatsek, & Rayner, 1997) or may fixate longer than do novices (e.g., Gilman & Underwood, 2003; Marcum & Duke, 2017; Savelsbergh, Kamp, Williams, & Ward, 2002; Savelsbergh, Williams, Kamp, & Ward, 2005). When the goal is to locate an item in a static scene (e.g., photograph or image) or identify differences between two scenes, experts typically make shorter fixations than do novices; however, when the task involves the ongoing assessment of a dynamic scene (i.e., video), experts typically fixate for longer than do novices. Gegenfurtner and colleagues (2011) caution that some of the observed differences may not only be attributable to task differences, but also may be further complicated by the small samples sizes that may contribute to sampling error. Regardless, most researchers agree that experts focus their gaze and attention on important and informative aspects of the scene more so than do novices.

THE HUMAN VISUAL SYSTEM

There is ample evidence in support of the notion that studying the eye movements of experts provides insight into expert thinking and decision making beyond what is available through behavioral observation alone. Understanding how the movements of the eyes indicate attention requires a brief explanation of the functions of the human visual system.

Vision involves the detection of light that is reflected off of items in the visual field. Incoming light rays pass through the lens of the eye and strike the retina, a densely packed carpet of cells lining the back surface of the eyes. The retina contains specialized photoreceptor cells that respond to different aspects of light: rods, of which there are about 120 million in each eye, are able to detect low levels of light and are responsible for peripheral vision and vision in dark environments; three types of cones, of which there are about 6 million, are tuned to different wavelengths and are responsible for perceptions of color; cones are also more responsive in bright light. There are also ganglion cells in the retina that detect levels of light and are associated with circadian rhythm, but these cells do not participate in vision.

A small spot near the center of the retina, called the fovea, comprises a large concentration of cones (Figure 1.1), and because of this concentration, visual images projected onto this area are the clearest and most focused. Images are less clear the farther away from the fovea their light strikes the retina (peripheral vision).

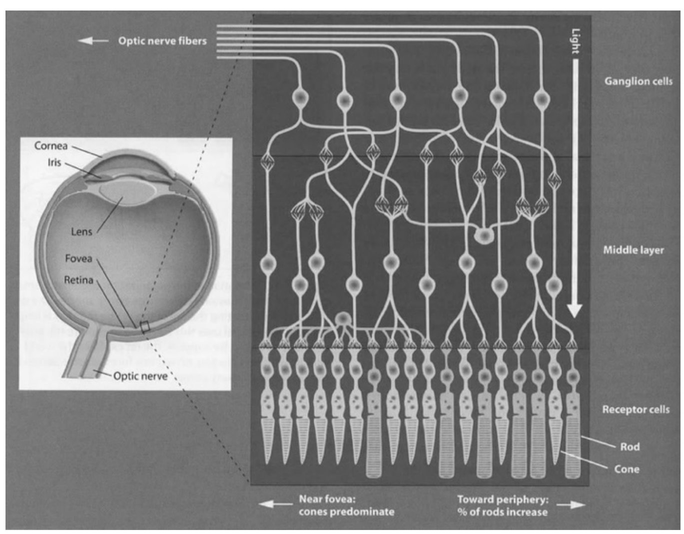


Figure 1.1: Diagram of the eye and fovea, including layers of the retina at the fovea. From "Sensation and Perception," by M. Gazzaniga, R. B. Ivry, & G. R. Mangun, 2013, Cognitive Neuroscience: The Biology of the Mind (4th ed.), p. 179. Copyright 2013 by W. W. Norton and Company.

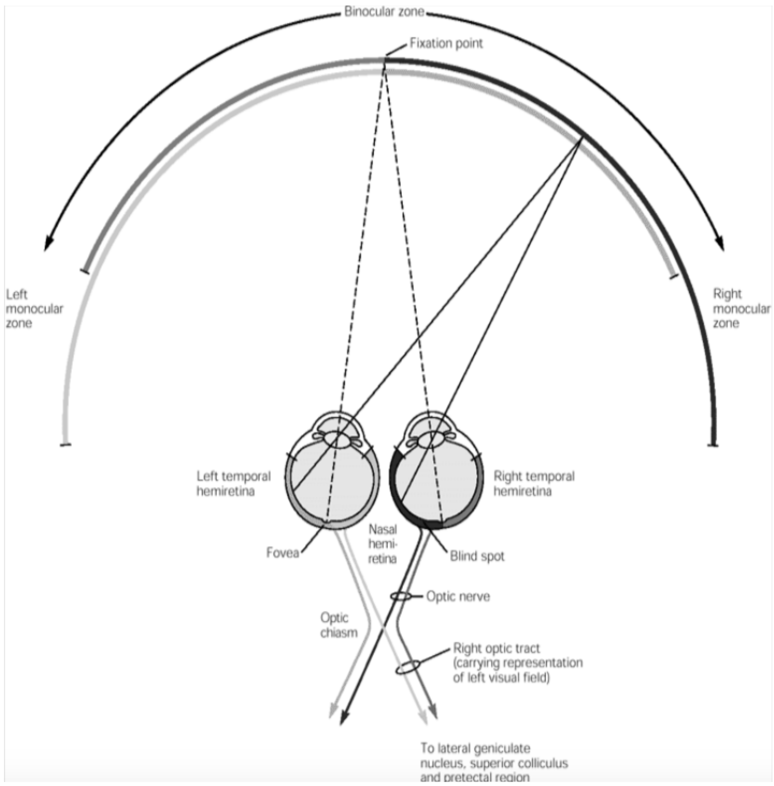


Figure 1.2: Diagram of the left and right visual fields. From "Central Visual Pathways," by E. Kandel, J. H. Schwartz, & T. Jessell, 2012, Principles of Neural Science (5th ed.), p. 524. Copyright 2012 by McGraw-Hill Education.

Each eye detects light from its respective side of the body, but the visual fields of each eye overlap at the center (e.g., the "left visual field" is made up of information from the left and right eyes) (Figure 1.2). Once light enters the eye and is projected onto the retina, signals from the rods and cones are transmitted through the optic nerve and across the optic chiasm. At the optic chiasm, information from the left visual field is projected to the right hemisphere of the brain for processing, and information from the right visual field is projected to the left side of the brain (Figure 1.3).

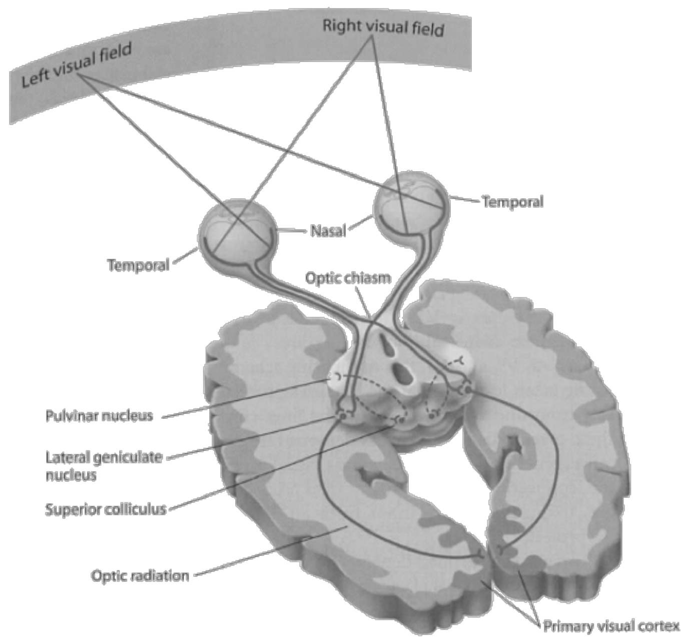


Figure 1.3: Diagram of the pathway of visual information from the visual field to the primary visual cortex (including optic chiasm). From "Sensation and Perception," by M. Gazzaniga, R. B. Ivry, & G. R. Mangun, 2013, Cognitive Neuroscience: The Biology of the Mind (4th ed.), p. 179. Copyright 2013 by W. W. Norton and Company.

After light enters the eye and the signal is transferred to the optic nerve, one of the first steps in visual processing in the brain occurs in the lateral geniculate nucleus (LGN). The LGN comprises six layers which are divided into two categories. The first two layers of the LGN, called magnocellular levels, connect to rods in the retina and are sensitive to slight contrasts of light. These cells are also sensitive to movement and the depth of the stimuli in the visual field, and they respond quickly to signals from the optic nerve. The last four layers of the LGN, called the parvocellular layers, connect to cones in the retina and are sensitive to color. The receptive field of these cells is smaller, and their response to stimuli is slower and more sustained than the quick responses of magnocellular cells. As signals move through the visual pathway, processing becomes more detailed and complex.

After processing in the LGN, visual signals move to the visual cortex, which is located in the posterior region of the brain (in the occipital lobe). The first posterior processing center is V1, the primary visual cortex. Like the LGN, V1 has six layers; the fourth layer receives magno- and parvocellular information from the LGN. Information from the retina is directly mapped onto V1, and projections from the fovea occupy a large portion of V1. The cells in V1 are primarily responsible for edge detection and recoding of visual information (so that it may be processed by areas farther down the visual processing stream). Information from V1 is then sent to V2, whose cells respond to spatial orientation and color. V2 sends information to V4, whose cells also respond to spatial orientation and color, but are sensitive to more complex and integrated visual features than are the cells in V2. Visual areas V1, V2, V3, and V4 all project to the middle temporal area (called MT or V5) (Figure 1.4). Cells in the MT are sensitive to motion in specific directions and speed when an object is moving (versus when the eye is moving).

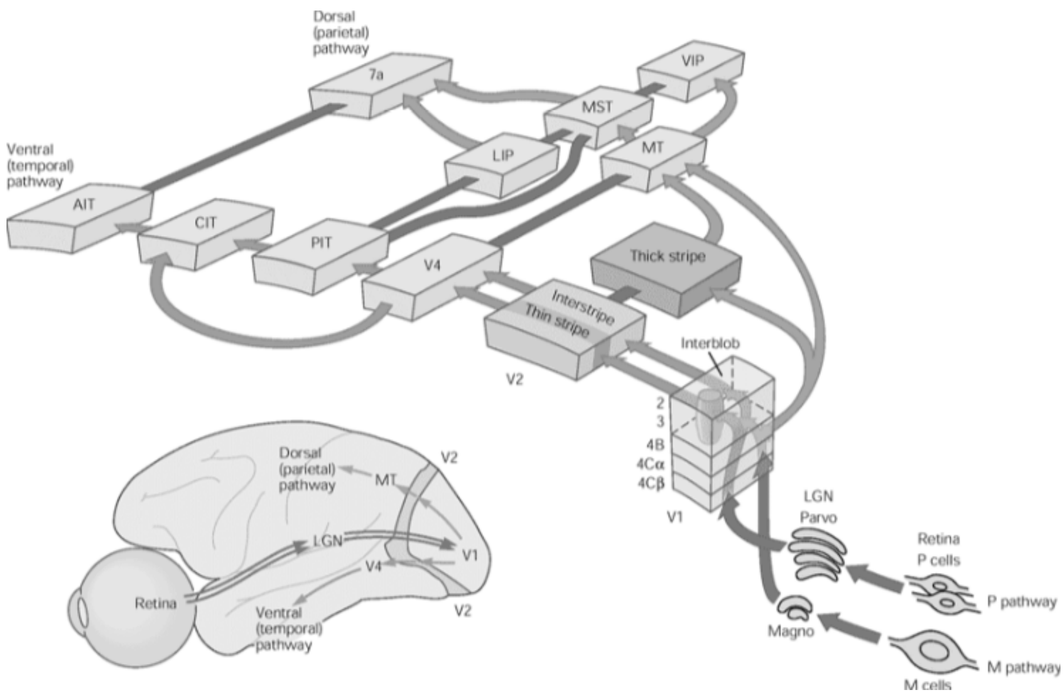


Figure 1.4: Diagram of the dorsal and ventral streams of visual information processing in the brain. From "Perception of Motion, Depth, and Form," by E. Kandel, J. H. Schwartz, & T. Jessell, 2012, Principles of Neural Science (5th ed.), p. 549. Copyright 2012 by McGraw-Hill Education. LGN: Lateral Geniculate Nucleus; V1-V4: Visual Areas 1-4; PIT: Posterior Inferotemporal Area; CIT: Central Inferotemporal Area; AIT: Anterior Inferotemporal Area; LIP: Lateral Intraparietal Area; MT: Middle Temporal Area; MST: Medial Superior Temporal Area. Arrows show the Dorsal (V1 → MT → MST) and Ventral (V1 → V4 → PIT → CIT → AIT) streams.

Once visual information is processed in areas V4 and MT, signals move to either the dorsal or ventral stream (Figure 1.4). In addition to sending information to MT, V4 also projects to middle-temporal areas, which are part of the ventral stream. The ventral stream of processing, also known as the "what" stream, is most responsible for further discerning the nature of objects (i.e., what they are). Each area in the ventral stream contains a representation of visual space, and the cells in each area are tuned to detect complex features, which allows for such complex processing as facial recognition. Cells in the ventral stream not only respond to objects' features but detect the significance of those objects based on the information stored in memory.

The majority of information from MT is projected through the dorsal processing stream, also known as the "where" or "how" stream. Signals from MT are sent to the medial superior temporal area (MST) and the lateral intraparietal area (LIP) in the parietal cortex. Cells in these dorsal areas are responsible for visually guided actions and for detecting the location of objects in space. These visual areas in the parietal cortex are connected to the motor cortex, which is involved in eye movements.

EYE MOVEMENTS

The area of the fovea encompasses about three degrees of the visual field (e.g., the size of a thumbnail at arm's length). In order to gather visual information efficiently, the eyes scan the environment and position the fovea on targets that require clarity of focus. Movements of the eyes are both involuntary (reflexive) and volitional. Some involuntary eye movements are initiated when the vestibular system (responsible for spatial orientation and balance) is activated, in order to stabilize the view when the body is in motion. When the head moves from left and right, for example, the eyes reflexively move contralaterally (i.e., right and left) so the image that is fixated remains stable. This vestibular ocular reflex (VOR) comprises multiple short "catch up" movements that keep the eye focused on visual targets. Other reflexive eye movements occur when the head remains stationary but the scene in front of the eyes moves. This optokinetic response

(OKR) is illustrated by looking out the window of a moving car, when the head remains stationary, but the eyes move to capture images of the moving scene.

Voluntary movements of the eye are reflective of allocation of attention. Quick movements called *saccades* reposition the eye at speeds of up to 500 degrees per second, lasting tens of milliseconds. These conjunctive movements (i.e., both eyes moving in the same direction) have a latency of about 150-200 ms from the onset time of when an individual is presented with a novel stimulus. Because saccades are so fast and can cover such large distances, their trajectory is not updated during the course of the movement. Instead successive saccades reposition the eyes once information is gathered from *fixations*, momentary pauses in the movement of the eyes.

Smooth-pursuit eye movements are also conjunctive but move much more slowly than do saccades, spanning about 35 degrees per second. Their trajectory is updated moment to moment based on visual feedback, increasing or decreasing the speed of motion to maintain focus on the moving target.

Shifting visual focus closer to or farther from the viewer requires disjunctive eye movements (eyes moving in opposite directions) to focus on the point of interest. This *vergence* is necessary to accommodate a change in the point of fixation in the depth of the visual field. Like conjunctive smooth pursuit movements, convergent and divergent movements are slower than saccades.

The purpose of all eye movements is to position the eyes to obtain relevant information that is useful in guiding decision making and action. Focused information is most often obtained during fixations, which typically last around 200 ms, but fixation durations vary greatly among environments and goals. There is evidence to suggest that fixation duration is correlated with cognitive processing (Bigand et al., 2010; Goldberg, 1999; Goldberg & Schryver, 1995), with longer fixation durations associated with more extensive (or effortful) processing.

ATTENTION

> Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatterbrained state which in French is called *distraction*, and *Zerstreutheit* in German. (James, 1890, p. 917-918)

Visual Attention

Attention can be thought of as the capacity to select information from the environment and the ability to use that information to guide subsequent actions. A given individual's focus of attention may be difficult to identify through behavioral observation, as behaviors may merely *suggest* attentional focus.

The human capacity for attention is limited, and given the array of stimuli present in nearly every environment, it is necessary to selectively attend to information that may be relevant to the task at hand. Much research has documented the severe limitations of human attentional resources (e.g., Bogler, Bode, & Haynes, 2011; Buschman & Miller, 2010; Corbetta, Patel, & Shulman, 2008; Kowler et al., 1995; Peelen & Kastner, 2014; Smith & Shenk, 2012). Perhaps the most vivid examples involve the phenomenon called change blindness. Experiments with photographs, video images, and even live interactions illustrate consistently that focusing attention on a particular element of an experience limits the capacity to notice changes in other elements. When changes are introduced in successive images (movie aficionados refer to these as “goofs”) and even in one’s interlocutor in an ongoing dialogue (Simons, 2000; Simons & Levin, 1997; Simons & Rensink, 2005), individuals are often incapable of detecting the change.

Limited attentional capacity is also illustrated in so-called dual-task (multitasking) experiments, which demonstrate that, rather than performing two attention-demanding tasks simultaneously, individuals actually alternate attention between competing tasks. This task switching introduces a refractory period that occurs with each switch, thus diminishing the capacity to perform either task optimally (Beilock, Carr, MacMahon, & Starkes, 2002; Dux, Tombu, Harrison, Rogers, Tong, & Marois, 2009; Redick et al., 2016).

Typical human beings can attend to stimuli perceived in any modality—auditory, visual, olfactory, tactile—but vision is the modality most often studied in experiments devoted to understanding attention. It is well understood that cognitive attention and eye movements are closely linked (e.g., Corbetta et al., 1998; Kowler et al., 1995; Orquin & Mueller Loose, 2013). Although it is possible to attend to a given visual stimulus by focusing the eyes on it (overt attention) or by using peripheral vision without a foveal fixation (covert attention), individuals tend to look toward and focus the eyes on that to which they are paying attention.

Investigations of brain activity during covert and overt attention tasks show that similar parts of the brain are active during both types of attention (Corbetta et al., 1998; Corbetta & Shulman, 2002; Kowler et al., 1995). Regions in the frontal eye field, parietal lobe, frontal cortex, and temporal cortex are active during covert attention as well as when participants move their eyes overtly to attend to a stimulus, though some researchers have argued that although the same regions of the brain are activated during overt and covert attending, different individual neurons respond in each case (Smith & Schenk, 2012).

Determinations of attention allocation and gaze location are based on competing internal and external inputs (Asplund, Todd, Snyder, & Marois, 2010; Buschman & Miller, 2010; Smith & Schenk, 2012). Attention tends to be drawn to stimuli in the environment that are salient or noticeably different from those around them in terms of size, color, orientation, or motion. Salient stimuli tend to perceptually "pop out" of the surrounding visual field. A red apple among a display of green limes, an individual walking quickly through a stationary crowd, and a sudden clap of thunder are all salient stimuli that are likely to capture attention. This "bottom-up" mechanism of allotting attention is stimulus-driven and nonvolitional (Bogler et al., 2011; Corbetta et al., 2008; Corbetta & Shulman, 2002; Theeuwes, 2010).

Attention allocation is also driven by internal goals through a "top-down" mechanism of target selection that directs attention to task-relevant stimuli, combining patterns and associations stored in memory to evaluate current stimulus inputs. Otherwise salient stimuli may be disregarded in the pursuit of information useful to accomplishing short- and long-term goals (Ballard, Hayhoe, Pook, & Rao, 1997; Shinoda, Hayhoe, & Shrivastava, 2001; Taya, Windridge, & Osman, 2013). In this way, top-down processing mitigates the effects of stimulus salience (bottom-up attention) (Nardo, Console, Reverberi, & Macaluso, 2016; Peelen & Kastner, 2014).

A vivid example of attention allocation driven by task goals is provided in an experiment reported in a paper cleverly titled “Gorillas in our midst” (Simons & Chabris, 1999). Participants watched a video of people in white and black shirts passing a basketball to other individuals and were asked to keep track of how many times people in white shirts passed the ball to each other. During the video, a woman dressed in a gorilla suit walked through the scene, paused to face the camera and beat her chest, and walked away. The gorilla was on camera for 5 s, but after completing the counting task, about half of the participants reported that they did not notice the intrusion. A gorilla walking through a basketball scene is, arguably, an unexpected and salient occurrence. However, since the participants in the study were assigned a behavioral goal relating to the players in white shirts, the salient occurrence escaped the notice of many participants. This result and the results of similar tests of inattentional blindness illustrate that stimuli related to the accomplishment of goals are noticed at the exclusion of stimuli that may otherwise be salient based on their inherent characteristics.

Much of the research on attention has focused on top-down and bottom-up processes, but more recently scholars have begun to investigate other drivers of attention, in particular the effects of previous reward (Anderson, 2015a, 2015b; Barbaro, Peelen, & Hickey, 2017; Le Pelley, Mitchell, Beesley, George, & Wills, 2016). It has been demonstrated in visual search tasks that stimuli associated with previous reward may attract attention more so than stimuli that are visually salient or stimuli that may contribute to the accomplishment of a momentary goal. In a visual search task in which the goal is to locate a green circle in a field of red, blue, and green circles and triangles, participants my devote attention to objects that have been associated with previous reward (blue shapes, for example) even though top-down processing would seem to direct attention to green shapes (related to the search goal) and bottom-up processes would seem to direct attention to red shapes (a result of their visual salience). This allocation of attention based on reward history has been observed even when the participant is unaware of the previous reward structure (Anderson, 2015a, 2015b; Theeuwes & Belopolsky, 2012).

Attentional processes are clearly complex and multifarious, and patterns of attention allocation change as individuals gain competence in various domains of activity, like sports, chess, cooking, or teaching (Corbetta & Shulman, 2002; Orquin & Mueller Loose, 2013). Experts presented with a novel scene make their first fixation more quickly and fixate task-relevant items more frequently than do nonexperts (Bilalić, 2018; Orquin & Mueller Loose, 2013), a result of their previous experiences and the shaping of attention through histories of rewarded actions. It appears that experts *look for* useful information based on pattern-recognition skills and domain knowledge, whereas novices tend to *look at* the environment, not aware of the defining features of meaningful, actionable stimuli.

Attention is connected to the visual pathway, because attention is crucial for visual processing, and in fact, goals related to what to look for and what motor commands to execute seem to be delivered through attentional pathways in the brain (Land, 2009; Land & Hayhoe, 2001). It was once believed that attention affected only cortical levels of visual processing, but researchers now believe that the lateral geniculate nucleus (LGN) is the first stage of visual processing affected by attention (Figures 1.3 & 1.4).

In addition to attention being linked to the visual pathway, there is evidence of a fronto-parietal network involved in attention. Studies of monkeys show that neurons in the frontal eye field (FEF) and the lateral intraparietal area (LIP) are active during attention and visual processing (Figure 1.5). The FEF and LIP guide eye movements in addition to playing a role in attention. LIP neurons respond selectively to objects that grab attention, which creates a salience map on the visual field. Manipulating the FEF and LIP in monkeys affects their target selection during search, and reward can affect responses in these areas as well. In humans, there are responses in the FEF, supplementary eye field (SEF), and the superior parietal lobule (SPL) when an individual attends to an area of an expected stimulus.

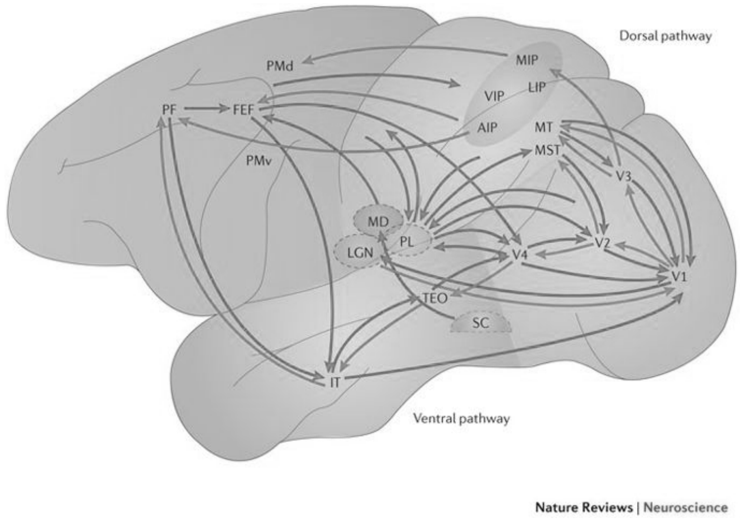


Figure 1.5: Diagram of the areas of the brain involved in attentional processing. From "Top-down influences on visual processing," by C. D. Gilbert & W. Li, 2013, Nature Reviews Neuroscience, p. 351. Copyright 2013 by Nature Reviews Neuroscience. LGN: Lateral Geniculate Nucleus; V1-V4: Visual Areas 1-4; PIT: Posterior Inferotemporal Area; CIT: Central Inferotemporal Area; AIT: Anterior Inferotemporal Area; AIP, LIP, VIP, MIP: Intraparietal Areas; MT: Middle Temporal Area; MST: Medial Superior Temporal Area; SC: Superior Colliculus; FEF: Frontal Eye Field; PF: Prefrontal Area. Arrows show pathways of signals through the visual and attention systems.

Auditory Attention

Organisms engage all of their senses in forming representations of their environments and making determinations about goals to pursue and the actions required to accomplish those goals. In addition to vision, audition is another important channel of information that contributes to decision making and action (Ferris & Sarter, 2008; Koelewijn, Bronkhorst, & Theeuwes, 2010; Nardo, Santangelo, & Macaluso, 2014). Given that the research presented in this dissertation assesses attention by monitoring eye movements during music tasks, it seems important to consider how the streams of visual and auditory perception interact.

When a stimulus that is first perceived through one modality attracts attention, other senses are often recruited to gain further information about the stimulus. The sudden presentation of a loud sound, for example, often prompts the orientation of gaze in the direction of the perceived sound source. A number of controlled investigations have been designed to assess connections between visual and auditory attention, and have revealed a great deal about the relationship between visual and auditory senses and their combined influence on attentional focus (Arndt & Colonius, 2003; Braga, Fu, Seemungal, Wise, & Leech, 2016; Corneil, Wanrooij, Munoz, & Opstal, 2002; Maddox, Pospisil, Stecker, & Lee, 2014; Nardo et al., 2014; Onat, Libertus, & König, 2007; Razavi, O'Neill, & Paige, 2007).

A common procedure for examining relationships between visual and auditory attention involves directing participants to locate a sound source when they are free to move their eyes and when they are asked to keep their gaze stationary. Participants locate sound sources more quickly and more accurately when they are free to direct their gaze. In addition, individuals use vision in response to auditory stimuli even when no relevant visual stimuli are present (e.g., participants move their eyes toward a sound source in a darkened room) (Arndt & Colonius, 2003; Braga et al., 2016; Corneil et al., 2002; Maddox et al., 2014; Nardo et al., 2014; Razavi et al., 2007) (for an alternative view, see Onat et al., 2007). In fact, being able to direct gaze toward a sound enhances discrimination of interaural levels of sound and time differences between two sounds, whereas simply directing auditory attention (and not gaze) does not enhance discrimination (Maddox et al., 2014).

Researchers studying multi-modal attention settings have found that participants presented with real-world scenes orient toward visual stimuli regardless of the absence or presence of auditory stimuli; participants preferred to attend to visual stimuli even if sound from another area of the scene was present (Braga et al., 2016; Nardo et al., 2014). Brain regions associated with auditory attention and visual attention overlap; areas in the frontal eye field (FEF), parietal lobe, middle frontal gyrus, and superior temporal gyrus all are involved in visual and auditory attention processes (Braga et al., 2016; Smith et al., 2009).

Many of the dimensions of attention allocation have yet to be fully characterized, but it seems clear that gaze serves as a useful indicator of cognitive attention, even in situations where sound is a primary stimulus feature (Arndt & Colonius, 2003; Braga et al., 2016; Corneil et al., 2002; Maddox et al., 2014; Nardo et al., 2014; Onat et al., 2007; Razavi et al., 2007). Although individuals can covertly attend to stimuli (i.e., focus cognitive attention without directing gaze to the attention target), in typical circumstances gaze is closely linked to attention; covert awareness is not the human default.

DECISION-MAKING

Choice making involves multiple processes, including attention, retrieval of relevant information from memory, formulating predictions, and assessing the effects of ongoing behavior. Features of the environment, priming, and internal goals, feelings, and personal preferences all influence decision-making and action (Payne, Bettman, & Johnson, 1992; Weber & Johnson, 2009). Yet, attentional resources are limited and the paths to decisions necessarily involve selective attention (Klink, Jentgens, & Lorteije, 2014).

Many decisions do not involve conscious deliberation, but are a product of implicit processes often referred to as intuition, feelings that are a product of external conditions and memories of past experiences. Intuition is an automatic process that is less cognitively demanding than is conscious deliberation (Glöckner & Witteman, 2010; Phillips, Fletcher, Marks, & Hine, 2016), and the benefits of intuitive decision-making versus conscious reflective decision-making vary with conditions and task demands (Acker, 2008; Phillips et al., 2016).

In contrast to algorithmic processes that identify explicit decision criteria, heuristics (often referred to as “rules of thumb”) serve to reduce cognitive load and guide thinking in the face of uncertainty (Glöckner & Witteman, 2010; Orquin & Mueller Loose, 2013; Payne et al., 1992). Heuristics serve as nonexplicit guidelines that tend to direct decision makers toward advantageous outcomes. One example is the “availability heuristic,” which prioritizes familiar (recallable) decision solutions as likely optimal. In circumstances that involve extensive complexes of interacting variables, heuristic approaches have been shown to outperform more deliberative approaches to problem solving and decision-making (Payne et al., 1992).

Consciously deliberated problem solving and choice making include consideration of possible options and assessment of their relative values and consequences. This reflective decision-making requires more time and is typically more cognitively demanding than intuition (see Orquin & Mueller Loose, 2013 for a review).

Common to all theories of decision-making is the notion that individuals survey the environment for information and fixate the stimuli that are thought to be useful in the decision-making process. Eye-tracking technology has revealed that individuals presented with an array of possible objects from which to choose are "visually biased" toward the eventual choice object. In multiple studies, participants fixated more frequently and for a longer duration on the item they eventually chose, and the first and last fixations often fell on the object of choice (Bird, Lauwereyns, & Crawford, 2012; Glaholt, Wu, & Reingold, 2010; Orquin & Mueller Loose, 2013; Pärnamets, Johansson, Gidlöf, & Wallin, 2016; Shimojo, S., Simion, Shimojo, E., & Scheier, 2003). This preferential looking serves as an indicator of preference, meaning the more an individual looks at something, the more she prefers it. The effect of preferential looking is even more pronounced in situations with more than two choices, and more complex scenes yield more fixations on fewer items to reduce the cognitive load of the decision maker. Prior learning also tends to lower the total number of fixations because stored knowledge allows for more efficient scene scanning (Bird et al., 2012; Glaholt et al., 2010; Orquin & Mueller Loose, 2013).

Although salience is a prominent factor in attention allocation and decision making, the environment, task demands, and internal goals are also influential, especially in complex natural environments. When the environment is complex and contains many choice options, decision-makers often screen for promising options, those that may satisfy task demands and accomplish goals. Many cognitive processes interact to influence judgment and decisions (Glaholt et al., 2010; Orquin & Mueller Loose, 2013;

Pärnamets et al., 2015), and eye movements can provide clues about the operation of these processes (Ballard, Hayhoe, & Pelz, 1995; Henderson, Hayes, Rehrig, & Ferreira, 2018; Land & Lee, 1994; Pelz & Canosa, 2001).

Experts recognize meaningful patterns and extract useful information from a visual and effectively apply the information in formulating courses of action (Bilalić, 2018; Randel, Pugh, & Reed, 1996). Randel and colleagues (1996), for example, found that in a simulated warfare scenario, experts devoted more time endeavoring to understand the situation, and once assessed, devised a successful course of action. Experts had richer prior experience available to assess the situation and create a solution. Novices presented the same scenario first devised lists of possible actions rather than spending time assessing the scene before determining a solution.

EYE MOVEMENTS IN NATURAL AND DYNAMIC SCENES

The systematic study of eye movements began at the end of the nineteenth century, when researchers employed mirrors and magnifiers to observe the movements of the eyes (Gassovskii & Nikol'skaya, 1941; Javal, 1879 as cited in Yarbus, 1967, p. 19; Newhall, 1928). Other researchers studied their own eye movements by observing the movements of afterimages following flashes of bright light. Exploiting the phenomenon that looking directly at a flash of bright light causes a lingering impression of the light after the flash subsides, researchers tracked and measured the movement of the after image, effectively learning about their own eye movements (Dodge, 1907; Duke-Elder, 1932; Helmholz, 1925 as cited in Yarbus, 1967, p. 13). Still other researchers employed various mechanical devices (e.g., levers or threads) attached to subjects' anesthetized eyes (Yarbus, 1967, p. 20).

As the study of eye movements evolved, measurement instruments became less physically invasive. Video recordings, still photography, measurements of electrical potentials (electrooculography), and measurements of reflected light on the cornea were employed to study gaze behavior. Alfred Yarbus, one of the leaders in pioneering eye movement research, built a number of devices for measuring eye movements and studying gaze behavior (1967, p. 29-58). Yarbus discovered that the fundamental purpose of saccades was to position the fovea over visual targets (1967, p. 129) and that fixations are indicators of attention (1967, p. 190). Yarbus noticed that individuals viewing complex scenes did not distribute their gaze uniformly across the images he presented. Instead, the eyes lingered on elements of the scenes that afforded the most information; the more information a scene contained, the longer the fixations lasted. Yarbus concluded that "Eye movements reflect the human thought processes, so the observers thought may be followed, to some extent, from records of eye movements" (1967, p. 190).

Recent developments in eye-tracking technology provide precise measurements of eye movements that contribute to the analysis of gaze targets and provide windows into attention. Employing eye-tracking technology as a component of behavior observation, rather than systematic observation and self-report data alone, may allow for more accurate inferences about how individuals perceive their environments and how individuals think about what they do (Hayhoe, 2017; Land, 2006; Tatler et al., 2011; Yarbus, 1967, p. 190). Fixation durations, for example, are interpreted as indicators of the time needed to locate, gather, and process relevant information from visual scenes (Droll, Hayhoe, Triesch, & Sullivan, 2005; Hayhoe, Bensinger, & Ballard, 1998; Hayhoe, Shrivastava, Mruczek, & Pelz, 2003; Land, Mennie, & Rusted, 1999).

Measures of fixation durations, sequences of fixations, repeated fixation targets, and other data from eye tracking have contributed to understanding the perceptual, cognitive, and motor processes involved in complex behavior (e.g., Hayhoe, 2017; Hayhoe & Ballard, 2005; Marcum & Duke, 2017; Yarbus, 1967, p. 190). Current theories of attention provide additional insight into these processes (Asplund et al., 2010; Bogler et al., 2011; Buschman & Miller, 2010; Corbetta & Shulman, 2002; Corbetta et al., 2008; Smith & Schenk, 2012; Theeuwes, 2010).

Researchers have extended Yarbus's pioneering work, studying eye movements in relation to natural environments and dynamic scenes (e.g., Hayhoe, 2017; Land, 2006; Tatler et al., 2011). Similar to research results obtained in laboratory settings, eye movements in natural environments depend strongly on the viewer's task and as well as features of the environment itself (Dorr, Martinez, Gegenfurtner, & Barth, 2010; Hayhoe et al., 2003; Hayhoe & Ballard, 2005; Jarodzka, Scheiter, Gerjets, & van Gog, 2010; Kandil, Rotter, & Lappe, 2009; Land, 2009; Land & Furneaux, 1997; Land & Hayhoe, 2001; Pelz & Canosa, 2001; Shinoda et al., 2001; Smith & Mital, 2013; Wang, Freeman, Merriam, Hasson, & Heeger, 2012). Results of several studies indicate that top-down goals guide attention more often than do salience or bottom-up processes (Henderson, 2003; Henderson et al., 2018; Land & Hayhoe, 2001; Smith & Mital, 2013; Turano, Geruschat, & Baker, 2003; Wallis & Bulthoff 2000), although Carmi and Itti (2006) found that the salience of motion can drive attention. The priority of top-down processes is explained in part by attention to task goals, which limits the perceptions of targets unrelated to the accomplishment of those goals. Focusing on goal-related targets and ignoring irrelevant ones, what is referred to as inattentional blindness, occurs in the context of both static images and dynamic scenes (Javoncevic, Sullivan, & Hayhoe, 2006; Wallis & Bulthoff, 2000).

A great deal of research devoted to the study of vision in relation to motor control indicates that fixations are almost always on task-relevant targets (e.g., Ballard et al., 1992; Ballard et al., 1995; Land & Hayhoe, 2001; Pelz & Canosa, 2001; Taya et al., 2013). Land (1999), in one of the first studies of eye movements in a natural environment, recorded eye movements as participants made a pot of tea. He discovered that the participants' gaze behavior was tightly linked to the motor movements involved in the task. Land and other researchers have found that when individuals complete everyday tasks like making tea or making a sandwich, the individual's eyes fixate relevant items in the environment just before they are needed to complete the task (Ballard et al., 1992; Ballard et al., 1995; Land & Hayhoe, 2001; Pelz & Canosa, 2001; Taya et al., 2013), referred to as just-in-time fixations.

Individuals engaged in various motor tasks first shift their bodies toward a relevant object, then move their eyes to fixate the object (guided by memory of the scene and current visual processing), then reach for the object. Once the object is grasped, the eyes move to the next location necessary for task completion (Land et al., 1999; Land, 2009; Land & Hayhoe, 2001). Land (2009) suggested that this sequence occurs because at the moment of grasping, another sense (e.g., tactile) can "take over" control of the task, freeing the eyes to fixate the next relevant target.

Researchers more recently have begun to study eye movements in dynamic real-world scenes (Carmi & Itti, 2006; Dorr et al., 2010; Jarodzka et al., 2010; Taya, Windridge, & Osman, 2012; Taya et al., 2013). Smith and Mital (2013), for example, presented videos of dynamic scenes while one group of participants was assigned a goal of locating particular items in a scene and another group was told to view the scene without an assigned goal. Fixation durations tended to be longer while watching the dynamic scenes than during static-scene viewing, regardless of task. Participants looking for a specific target scanned across the scene, whereas those without a specific goal tended to select a few areas of the scene for further study and spent the most time fixating objects in those areas.

EYE MOVEMENTS DURING TEXT AND MUSIC READING

A great deal of research has deployed eye tracking technology in the study of reading text and to a lesser extent in reading music. Many early investigations were conducted in controlled settings in which participants briefly viewed images while their eye movements were recorded (e.g., Sloboda, 1974; Weaver, 1943). The technological limitations of early recording devices yielded imprecise data, but by the 1980s computers allowed for more accurate analyses (Goolsby, 1994a).

Reading music is in many ways similar to reading English text in that both tasks involve a sequential progression from left to right across a printed page and down through successive lines. Letters, words, and musical symbols alike are not perceived as isolated elements but are processed in groupings that represent familiar and predictable configurations (Arthur, Khuu, & Blom, 2016; Goolsby, 1994b; Kinsler & Carpenter, 1995; Rayner, 1998).

Music notation differs from text in important ways, of course, as the symbols of music notation convey information about multiple dimensions of sound (e.g., pitch, duration, articulation) that must be integrated by the reader. Unlike printed prose, music also unfolds in measured time and thus requires a (usually) consistent rate of processing. Studying fixation and saccade data provides insight into music-readers' attention, perception, and cognitive processing.

Musicians' perceptual spans (the amount of music that can be clearly seen and processed) are about 4-5 notes to the right of the point of fixation, though the widths of perceptual spans can be increased with training (Burman & Booth, 2009; Goolsby, 1994b; Weaver, 1943). Musicians' perceptual spans also stretch vertically, especially for performers who play multi-stave music. Musicians who play piano, harp, string instruments, and percussion instruments often play multiple notes (and even multiple lines of music) at one time, which requires the perception of note to the right of the fixation point as well as notes above or below the fixation points.

Fixation durations during music-reading tend to be longer than fixations during text reading, typically 350-400 ms (Burman & Booth, 2009; Goolsby, 1994b; Rayner & Pollatsek, 1997; Weaver, 1943). Because fixation duration is related to cognitive processing time, a longer mean fixation duration during music-reading, as opposed to reading text, may be indicative of the multiple dimensions of sound represented by a single note or note grouping.

Perhaps as a result of their greater familiarity with musical conventions and patterns in music structures, expert musicians' fixations are typically shorter than are novice musicians' (Goolsby 1994a, 1994b). Musicians typically fixate notes ahead of the point of performance. As in text-reading, these fixations facilitate a steady flow of incoming information and, particularly in music, afford time to initiate motor commands to produce the music being read. Music reading also includes more backward (toward the left side of the page) saccades than does text reading (Cara & Gomez, 2016; Goolsby, 1989). One explanation for these regressive saccades is that they serve a confirmatory function; that is, musicians look back to the point of performance to confirm the accuracy of performed notes.

It is perhaps unsurprising that expert musicians tend to look farther ahead in their music than do novice musicians (Furneaux & Land, 1999; Madell & Héébert, 2008; Sloboda, 1974). In experiments that remove notation from view while a participant is in the midst of reading, experts are able to play longer and more accurately than are novices.

As noted previously, expert music readers do not process individual symbols in isolation, but recognize patterns in notation that form "chunks," which is consistent with expert processing in multiple domains (Bilalić, 2018, p. 144-145; Chase & Simon, 1973). This quick apprehension of patterned symbols leads experts to require shorter fixation durations than are required by novices (Waters, Underwood, & Findlay, 1997; Waters & Underwood, 1998). Novice musicians are less apt to recognize patterns or chunks and tend to read music note-by-note (Arthur et al., 2016, Gilman & Underwood, 2003), thus limiting their capacity to look ahead as attempting to recall individual pitches strains working memory capacity.

ANALYSES OF GAZE IN MUSIC TEACHING

Given what we know from research in expertise, attention, and eye-movements, employing eye tracking as a means of studying music teaching expertise seems to be a worthwhile endeavor. Researchers have used eye-tracking technology to study expertise in many domains, although eye-tracking research in music to date has mostly been limited to studies of music reading (Arthur et al., 2016; Burman & Booth, 2009; Cara & Gomez, 2016; Drai-Zerbib & Baccino, 2014; Furneaux & Land, 1999; Gilman & Underwood, 2003; Goolsby 1989, 1994a, 1994b; Hoppe, Splittstößer, Fliessbach, Trautner, Elger, & Weber, 2014; Kinsler & Carpenter, 1995; Madell & Héébert, 2008; Penttinen, Huovinen, & Ylitalo, 2013; Rayner & Pollatsek, 1997; Silva & Castro, 2018; Sloboda, 1974; Truitt et al., 1997; Waters & Underwood, 1998; Waters et al., 1997; Weaver 1943).

Marcum and Duke (2017) recently pioneered the use of eye-tracking technology to study music teacher perception in several live teaching scenarios. In one study the gaze patterns of an artist-level string teacher and an advanced graduate student were recorded as they observed and taught lessons to two different students. Each teacher first watched one of her own private students (i.e., a familiar student) play a short piece, and then taught a 5-minute lesson following the performance based on what she observed. The two teachers, both of whom were identified by the authors as experts, then followed the same procedures with the other teacher's student (i.e., a novel student). After each lesson, the teachers verbally explained their instructional goals.

In subsequent analyses of the two teachers' gaze patterns, Marcum and Duke found that the artist-teacher and advanced graduate student performed similarly when watching and teaching their own students, in that each fixated locations that clearly corresponded to their stated lesson goals in each of several rehearsal frames in each lesson. The artist-teacher defined goals related to the student's bow hold and bow alignment, and she primarily fixated the bow contact point and the bow hand during the initial performance and during the lesson. The advanced graduate student defined goals related to intonation, and she frequently fixated the fingers of her student's left hand.

When watching and teaching the novel student, the artist-teacher's gaze behavior was remarkably similar to her gaze behavior when teaching her own student, in that her fixations were consistently related to her proximal performance goals in each rehearsal frame. But the advanced graduate student fixated numerous locations on the student's body and on the instrument that were not germane to the instructional goals she had identified in the post-lesson interview.

Comparisons of the two lessons with the familiar students, in which the gaze behaviors of the two teachers were quite similar, and the two lessons with the unfamiliar students revealed important differences in visual attention between the expert and the advanced graduate student. The artist-teacher's gaze with both students revealed a consistent approach to gathering information that guided her decision making, including the formulation of appropriate proximal goals. Her patterns of gaze were indications of a well-established and deeply-practiced approach to pedagogy that was evident even in circumstances that were somewhat unfamiliar. As was the case in her lesson with her own student, her lesson with the unfamiliar student applied the same features of attention allocation that were consistent with her instructional goals.

Although the advanced graduate student behaved similarly when teaching her own student, her approach with the unfamiliar student was quite different, and her patterns of fixation seemed less directed by a priori hierarchies. The gaze behavior of the artist-teacher in both lessons and the behavior of the advanced graduate student in the lesson with her own student might by described as *looking for* information that was tightly linked to the accomplishment of tangible performance goals. The gaze behavior of the advanced graduate student observing and teaching a student for the first time might be described as less systematic, *looking at* rather than *looking for*.

Marcum and Duke also compared four string teachers with different levels of experience and expertise teaching brief lessons to their own students. An artist-level string teacher, and advanced graduate student, an upper-level undergraduate music education major, and lower-level undergraduate music education major first observed one of their own students perform a short melody and then taught a 5-minute lesson. As in the earlier study, the participants were asked after the lesson about their instructional goals, and their eye-tracking data were analyzed in relation to the goals they identified.

There were clear differences in gaze behavior among the four teachers. Perhaps most notable are the relationship between percentages of fixation duration on relevant targets in each rehearsal frame. The two most experienced and skillful teachers fixated targets that were consistent with their instructional goals. In particular, they fixated targets *after* giving directives related to that goal, what Marcum and Duke called Follow-up Fixations (FUFs), and FUFs were much less frequent and much shorter, when they did occur, in the lessons of the less experienced teachers. In stark contrast, the least experienced and least skillful teachers spent considerably less time fixating visual targets that pertained to their instructional goals.

SUMMARY AND RESEARCH QUESTIONS

Though previous research has revealed a great deal about expert teacher behavior and about teachers' perceptions of their own behavior, there remains a need to illuminate the underlying processes of teacher thinking and perception, in particular the allocation of attention during the process of music instruction. Currently available technical resources show great promise in extending our understanding of musical thinking through the analysis of eye movements in naturalistic environments with authentic musical tasks. Marcum and Duke's research into attention allocation in music teaching represents the first successful implementation of eye-tracking technology in this effort. Their research began to unveil aspects of teacher thinking that had not been observed in earlier work.

The two descriptive studies in this dissertation represent a continuation of Marcum and Duke's applications of eye tracking technology, this time in varied musical tasks, comparing the gaze patterns of experts with those of other musicians. The first, a study of score reading by wind conductors, reveals patterns of music reading in a full-band score that have yet to be characterized in the literature. The second, a study of gaze behavior during observations of individual performances in varied contexts, including music performance, sport, and ballet, illustrates the important differences between expert and novice perceptual approaches and the extent to which expertise is characterized by a tight focus on targets critical for successful task completion. Both of these studies also demonstrate the viability and usefulness of eye tracking as a method to study music teacher expertise in a variety of contexts.

These investigations were designed to answer the following questions:

In what ways and to what extent do the eye movements of expert and novice conductors differ as they read full ensemble scores in measured time (in tempo) with and without listening to a recording of the music?

If such differences exist, what do they reveal about the attentional, conceptual, and cognitive processes engaged when reading and hearing music?

In what ways and to what extent do the eye movements of expert and nonexpert performers and teachers differ as they observe video recordings of instrumentalists performing music and others engaged in other physical skills (juggling, batting in baseball, and ballet)?

If such differences exist, what do they reveal about the attentional, conceptual, and cognitive processes engaged when observing skilled behavior?

Chapter II: Eye Movements of Conductors Reading Music Scores

Recent human history has witnessed the creation of symbolic representations of objects, events, emotions, and ideas that occur in the natural world and in the lived experiences of human beings (DeHaene, 2009). The inception of language spawned the creation of written text and the accompanying challenges of encoding and decoding visual representations of auditory phenomena and their associated meanings (DeHaene, 2009). This in turn has led to an interest in examining the eye movements of text readers in an effort to discern the perceptual-cognitive components of reading (e.g., Buswell, 1921; Just & Carpenter, 1980; Rayner, 1998; Silva, Reis, Casaca, Petersson, & Faísca, 2016).

It is now well documented that readers do not fixate individual letters or even individual words, but instead view larger structures (see Rayner, 1998 for a review). The "perceptual span" in reading written English is typically 9-13 characters to the right of the fixation point (i.e., in the direction of the text-reading), and readers' fixations, which typically average between 200-250 ms in duration, tend to occur ahead of the point of speech when reading aloud (Buswell, 1921; Silva et al., 2016) and ahead of the point of comprehension when reading silently (Arthur et al., 2016; Burman & Booth, 2009; Cara & Gomez, 2016; Goolsby, 1994b; Hoppe et al., 2014; Penttinen et al., 2013; Rayner, 1998; Rayner & Pollatsek, 1997; Silva & Castro, 2018).

Music reading differs from text reading in important ways, of course, as music symbols convey multiple dimensions of sound (e.g., pitch, rhythm, style) and music unfolds in measured time (Goolsby, 1989). As a consequence, average fixation durations during music reading tend to be longer than those in text reading, typically between 350-400 ms (Burman & Booth, 2009; Goolsby, 1994a, 1994b; Land & Furneaux, 1997; Rayner & Pollatsek, 1997; Weaver, 1943). Just as text-readers perceive more than one letter or word in a single fixation, musicians see and perceive more than one note in a single fixation. Musicians' perceptual spans are typically about 4-5 notes to the right of a fixation point, although this span can be increased with training (Burman & Booth, 2009; Goolsby, 1994b; Weaver, 1943).

As is true in text reading, music reading is characterized by fixations ahead of the music itself, which during music performance affords time to process notation and initiate motor commands while maintaining a steady pulse. Perhaps not surprisingly, expert musicians tend to look farther ahead in their music than do novice musicians (Furneaux & Land, 1999; Goolsby 1994a, 1994b; Madell & Hebert, 2008; Sloboda, 1974).

No published research to date has examined the eye movements of conductors reading full ensemble scores, which is a fundamental element of score study, ensemble conducting, and rehearsing. Although there exists some information about eye movements while reading single lines of music or piano scores, conductors' allocation of cognitive attention has yet to be characterized in more complex musical with multiple voices present.

In an effort to identify features of musical thinking that differentiate novice and expert conductors, we undertook a descriptive study to analyze the eye movements of expert and novice conductors while they read full ensemble scores with and without hearing a recording of the printed music. Conductors read silently, without conducting, creating an experience typical of score study and one that resembles silent text reading.

METHOD

Participants

Participants in our convenience sample were highly-skilled faculty conductors (n = 2, both males), doctoral-student conductors (n = 2, one male), and undergraduate student conductors (n = 2, one male), all of whom were affiliated with the Sarah and Ernest Butler School of Music at The University of Texas at Austin. Doctoral students were enrolled in the graduate program in wind conducting; undergraduate participants were upper-level music education students who had completed at least one instrumental conducting course. The two undergraduate participants were both experienced musicians and considered to be at the top of their music education cohort.

All procedures were approved by the Institutional Review Board for human subjects research at The University of Texas at Austin. Participants gave informed consent and received no compensation for their participation. Each participant completed an individual eye-tracking session of approximately 45 minutes in duration.

Procedure

Participants sat in a chair positioned in front of a music stand and adjusted the height and angle of the stand to allow for comfortable page turns. Participants then donned Pupil Labs™ eye-tracking glasses, and the primary author adjusted the cameras that monitor the position of the eyes and a forward-facing camera that records the visual scene from the perspective of the participant. After adjusting the glasses, Pupil Labs™ Capture software was initiated to begin recording the session.

Participants read excerpts from one familiar and one unfamiliar wind ensemble score. The excerpts were from the *March* from Gustav Holst's *First Suite in E-flat*, mm. 97-139 (familiar to all participants), and *Movement 4* from Eric Ewazen's *Celestial Dancers*, mm. 52-82 (unknown to all participants prior to the study). The dimensions of the score pages were 11 x 14 in. The Holst and Ewazen scores both contained 26 instrumental parts; there were more individual percussion parts in the Ewazen score than in the Holst score. Both scores contained a melody line played by multiple instruments, 2-3 harmony or countermelody lines played by multiple instruments, a bass line played by multiple instruments, and percussion parts. Copies of the scores are presented in Appendix A.

Participants read each score excerpt twice: once while listening to an audio recording and once while listening to a metronome set to the same tempo as the recording of each piece. The order of presentation was the same for all participants: (1) Holst with metronome (HM), (2) Holst with recording (HR), (3) Ewazen with metronome (EM), and (4) Ewazen with recording (ER). Participants read the Holst and Ewazen scores with the metronome before reading with the audio recording so that the audio recording did not contribute to the auditory image of the music when reading with the metronome, and given the novel experience of wearing eye-tracking glasses, it seemed most appropriate to begin the sessions with a familiar, rather than unfamiliar score.

The sound of the music and metronome played through high quality stereo loudspeakers set at a moderate volume and positioned approximately 3 ft in front the participant. At the conclusion of the music-reading tasks, participants answered a series of questions about their typical score-study practices and how they thought the different reading conditions (metronome vs. recording and familiar vs. unfamiliar music) affected their score reading.

Data Analysis

We calibrated the eye-tracking recordings post hoc using offline calibration[1], and plotted each fixation onto printed copies of the scores to create visual representations of participants' scan paths (i.e., the sequences of consecutive fixations), including progressive (rightward-moving) and regressive (leftward-moving) saccades (Figure 2.1). We calculated fixations as video frames in which the eye moved slower than 40 degrees per second of velocity. In most contexts, human perception of a visual stimulus requires a fixation of at least 150 ms in duration. After setting velocity parameters, we set the range

[1] When correctly calibrated, Pupil Labs™ glasses record fixation points to an accuracy of 1-degree visual angle. Each participant completed four calibration sequences (one before each score excerpt) during the recording session, which were re-analyzed post hoc to achieve optimal calibration.

for analyzing fixations to 200-4000 ms.[2] Pupil Labs™ gaze analysis software merges data from the eye and scene cameras to create a video of scan paths of participants' eye movements that are superimposed over the scene (which in this study, showed the score). We used Audacity™ sound editing software to mark the onset timing of each fixation in relation to the ongoing music.

Measure number and beat locations of each fixation were recorded, and fixation locations were coded according to the instrument, line, and function (e.g., entrance, release, phrase beginning). The Holst excerpt is written in cut time with a two-beat pulse, and for the purposes of determining fixation synchrony, we labeled each half note as a beat when analyzing temporal alignment and saccade distance. The Ewazen excerpt is written is 9/8 with a three-beat pulse, and we labeled each dotted quarter note as a beat. The graphs in figure 2.2 show one faculty participant's data during both score readings.

[2] In most contexts, human perception of a visual stimulus requires a fixation of at least 150 ms in duration, and mean durations of fixations music reading have been reported between 350 and 400 ms. We analyzed our data using minimum fixation thresholds of 150 ms and 200 ms, and found that the lower threshold captured, at most, one or two additional fixations in each reading; the results seemed most interpretable using the 200 ms threshold. Even during fixations, the eyes are not entirely stationary, but engage what are referred to as micro-saccades. These micro-saccades are a common feature of human vision, yet analyses of gaze typically ignore them, focusing instead on fixations within defined temporal and spatial ranges.

(a) ***Faculty 1 Holst Readings*** (b) ***Faculty 1 Ewazen Readings***

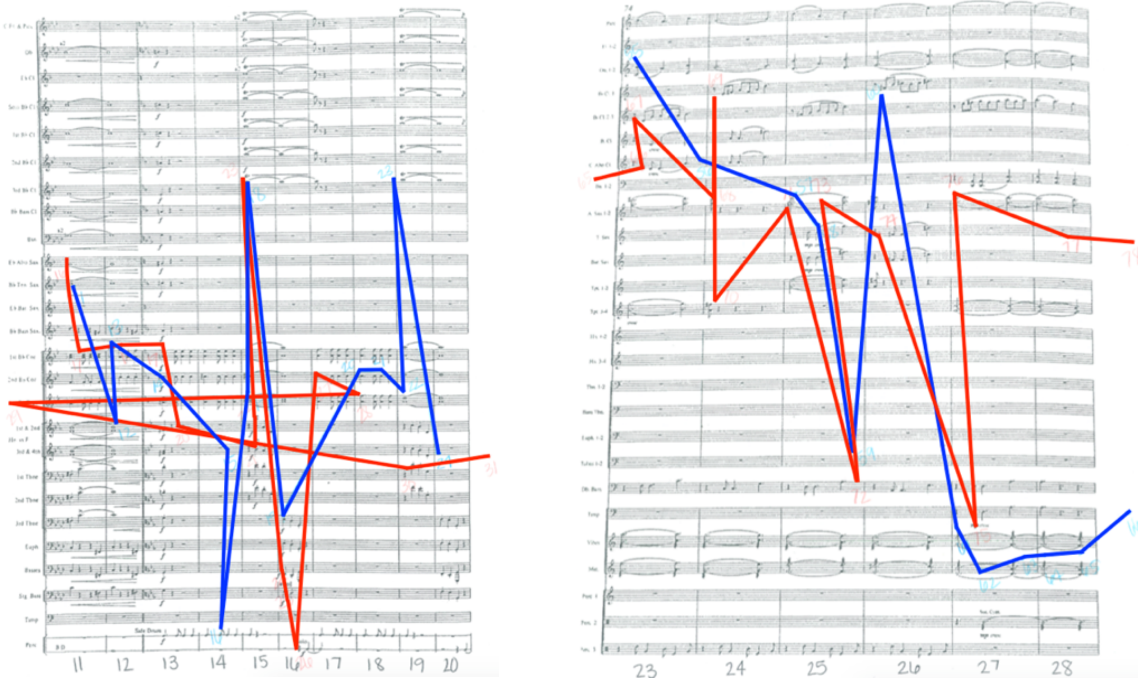


Figure 2.1: Sample scan paths comparing individual participant data during Holst and Ewazen readings. The printed music scores (a, b) display the scan paths of one faculty conductor while reading along with the metronome (red lines) and while reading listening to the recording (blue lines).

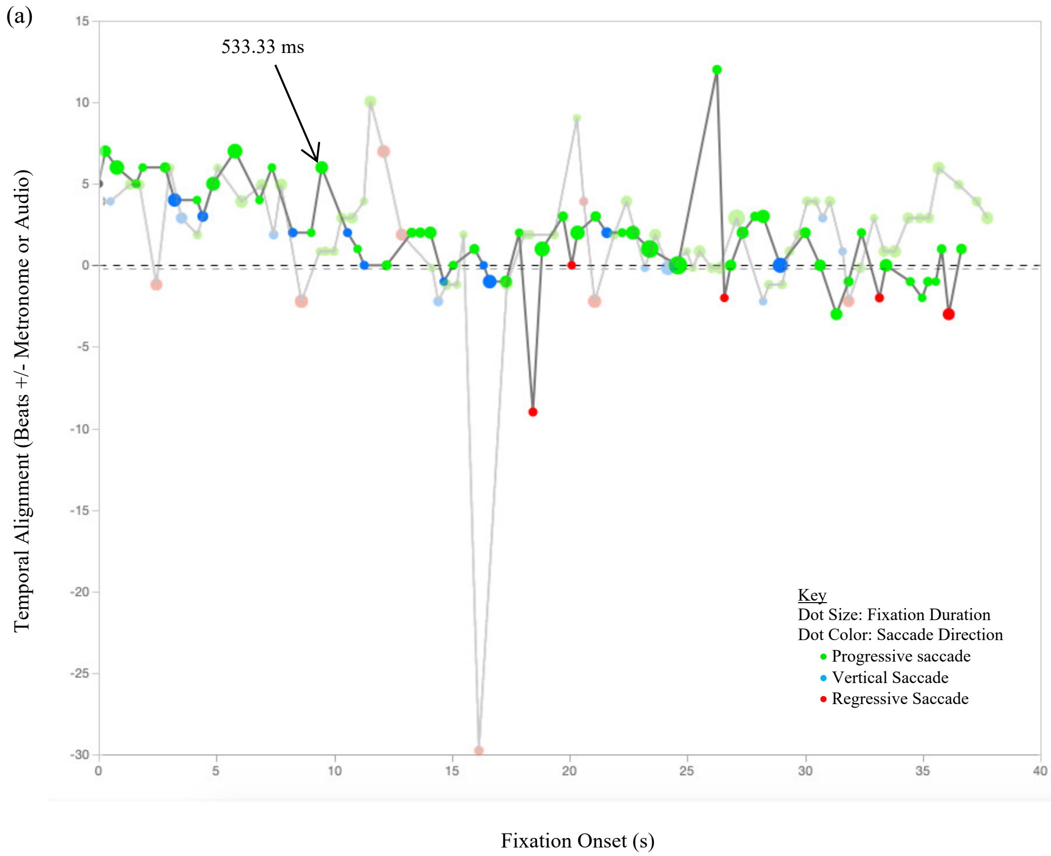


Figure 2.2: Sample graphs comparing individual participant data during Holst and Ewazen readings including temporal alignment, fixation duration, saccade direction, and fixation onset time. Graphs a and b display the timing of each fixation relative to the unfolding music in the reading with the metronome (greyed lines) and the reading with the recording (opaque lines). The y axis indicates the timing of each fixation relative to the recording or metronome, expressed in musical beats. Time in seconds is represented on the x axis. Each point represents one fixation; green points indicate that the fixation was approached with a progressive saccade (i.e., an eye movement from left to right, in the direction of the musical progression); red points indicate regressive saccades; and blue points indicate vertical saccades (i.e., an eye movement to a different line in the score on the same beat). The size of each point reflects the duration of each fixation; larger points indicate longer fixations.

(continued)

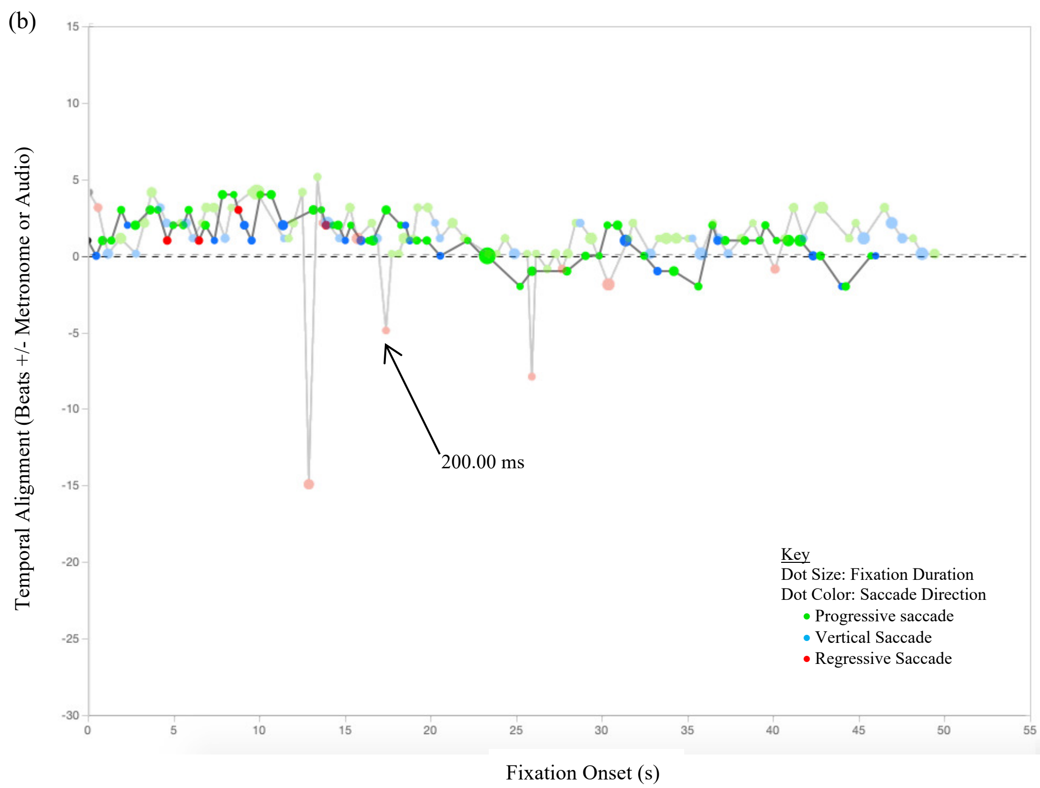


Figure 2.2: Sample graphs comparing individual participant data during Holst and Ewazen readings including temporal alignment, fixation duration, saccade direction, and fixation onset time (continued).

RESULTS

The dimensions of data we report, which include frequencies, durations, and timing of fixations; distances and directions of saccades; and narrative descriptions of scan paths (i.e., where in the score participants fixated), demonstrate that gaze behavior varied systematically by level of experience (Table 2.1). As might have been expected, the gaze behavior of the graduate conductors was much like that of the faculty conductors'. The undergraduate conductors' gaze behavior, especially in terms of scan paths, was often unlike the behavior of faculty and graduate conductors, though some individual fixation measures resembled those of the more-experienced participants.

We classified fixations as either informative or noninformative, depending on their location in the score and their timing relative to the ongoing music. We defined informative fixations as *anticipatory or coincident fixations* (1) at points in the score where some component of the music *began* or otherwise *changed* (e.g., entrances of new voices in the texture, releases at phrase endings, changes in articulation) and (2) *ongoing line fixations* at other locations which indicated that the participant was reading successive tones in an ongoing part (e.g., participant fixates beginning of a melody in the clarinet line and then fixates points along that same line). Fixations so defined are distinct from noninformative fixations that were *behind the metronome or recording* or offered little meaningful information to the viewer (e.g., blank measures, margins, a jump the middle of an ongoing phrase, repeated pattern).

Individual faculty and graduate conductors' two readings of each piece (with a metronome or with a recording) produced similar gaze patterns. Participants most often fixated events in the score that were musically informative several beats in advance of their occurrence in time with the metronome or audio recording. There was somewhat more variation in gaze patterns between the readings with the metronome and readings with the recording among the graduate participants than among the faculty participants—the faculty participants looked more frequently at similar targets in the metronome and audio readings than did the graduate participants.

Undergraduate's scan paths, fixation durations, and numbers of fixations varied between the two readings (metronome and recording) for both pieces. Undergraduates tended to fixate events after they had occurred and often fixated locations in the score with little meaningful information. We report the details of our analysis below.

Table 2.1

Mean Fixation Data for Four Score Readings: Rate, Duration Median, Percent of Progressive Saccades, Saccade Distance, Temporal Alignment with Ongoing Music, and Percent of Line-Change Fixations

		Holst Metronome Reading	Holst Audio Reading	Ewazen Metronome Reading	Ewazen Audio Reading	Overall M	Overall SD[a]
Fixation Rate (fixations per sec)	F 1	1.81	1.68	1.75	1.58	1.71	0.10
	F 2	1.77	1.83	1.92	1.78	1.83	0.07
	G 1	1.50	1.45	1.41	1.53	1.47	0.05
	G 2	1.72	1.80	1.67	1.58	1.69	0.09
	U 1	1.80	1.67	1.42	1.53	1.61	0.17
	U 2	1.44	1.54	1.67	1.66	1.58	0.11
Fixation Duration Median (ms)	F 1	300.00	300.00	266.67	266.67	283.34	19.24
	F 2	333.33	366.67	333.33	333.33	341.67	16.67
	G 1	383.33	408.33	433.33	400.00	406.25	20.83
	G 2	333.33	300.00	266.67	300.00	300.00	27.21
	U 1	322.22	333.33	366.67	333.33	338.89	19.25
	U 2	358.33	366.67	316.67	300.00	335.42	32.18
Percentage Progressive Saccades	F 1	75.36	75.81	60.92	70.42	70.63	6.92
	F 2	69.12	77.94	61.96	67.07	69.02	6.66
	G 1	63.64	69.09	69.70	76.81	69.81	5.40
	G 2	75.00	64.18	67.53	63.77	67.62	5.20
	U 1	77.92	78.69	74.24	76.39	76.81	1.96
	U 2	69.74	77.19	61.33	68.83	69.27	6.49

(continued)

Table 2.1 *Mean Fixation Data for Four Score Readings* (continued)

Saccade Distance Median (beats)	F 1	2.00	3.00	1.00	1.00	1.75	0.96
	F 2	3.00	3.00	1.00	1.00	2.00	1.15
	G 1	3.50	3.00	1.00	1.00	2.13	1.31
	G 2	3.00	2.00	1.00	1.00	1.75	0.96
	U 1	2.00	3.00	1.00	1.00	1.75	0.96
	U 2	2.00	3.00	1.00	1.00	1.75	0.96
Temporal Alignment Median — (+ or - number of beats)	F 1	1.00	1.00	1.00	1.00	1.00	0.00
	F 2	3.00	2.00	3.00	2.00	2.50	0.58
	G 1	2.00	3.25	-2.00	1.00	1.06	2.24
	G 2	2.50	3.00	3.00	3.00	2.88	0.25
	U 1	-0.50	2.00	2.00	2.50	1.50	1.35
	U 2	-14.00	1.00	4.00	1.00	-2.00	8.12
Percentage of Informative Fixations	F 1	75.36	69.35	80.46	78.87	76.01	4.92
	F 2	82.35	73.53	73.91	70.73	75.13	5.02
	G 1	61.82	60.00	21.21	65.22	52.06	20.68
	G 2	83.82	83.58	76.62	79.71	80.93	3.44
	U 1	41.56	72.13	62.12	69.44	61.31	13.83
	U 2	15.79	73.68	69.33	76.62	58.86	28.87
Percentage of Line-Change Fixations	F 1	63.77	62.90	75.86	78.87	70.35	8.20
	F 2	72.06	77.94	80.43	80.49	77.73	3.96
	G 1	54.55	59.62	54.55	55.07	55.95	2.46
	G 2	73.53	73.13	85.71	81.16	78.38	6.12
	U 1	51.95	67.21	42.42	51.39	53.24	10.28
	U 2	55.26	50.88	40.00	45.45	47.90	6.62

Note. Progressive saccades move the eyes to the right in the direction of the music. Temporal Alignment refers to the timing of fixations relative to the beat of the metronome or recording. Temporal Alignment and Saccade Distances were calculated in terms of musical beats with 2 beats per measure during the Holst readings and 3 beats per measure during the Ewazen readings. Tables of each individual measure have been provided in the following paragraphs for ease of reference. F1 = Faculty 1, F2 = Faculty 2, G1 = Graduate 1, G2 = Graduate 2, U1 = Undergraduate 1, U2 = Undergraduate 2.
[a] The standard deviations in this column are the SDs of the medians of the four score readings for each participant.

Numbers of Fixations

Table 2.2 presents mean values for fixations and saccades for faculty, graduate, and undergraduate participants in each of the four readings. As the two excerpts were different durations, we report fixations per second (fps) rather than total fixations for each reading. Fixations per second for individual conductors in both Holst readings and both

Ewazen readings were quite similar. Overall, participants fixated more frequently during the Holst readings than they did during the Ewazen readings. The one exception was Faculty Participant 2 (F2), who fixated more frequently during the EM reading. Overall, the faculty fixated more frequently than did the graduates and undergraduates across all readings. In three of the four readings, with the exception of the HR reading, the graduate participants fixated less frequently than did the undergraduates.

Table 2.2

Mean Fixation Data for Four Score Readings: Fixation Rate (Fixations per Second)

		Holst Metronome Reading	Holst Audio Reading	Ewazen Metronome Reading	Ewazen Audio Reading	Overall M	Overall SD
Fixation Rate (fixations per sec)	F 1	1.81	1.68	1.75	1.58	1.71	0.10
	F 2	1.77	1.83	1.92	1.78	1.83	0.07
	G 1	1.50	1.45	1.41	1.53	1.47	0.05
	G 2	1.72	1.80	1.67	1.58	1.69	0.09
	U 1	1.80	1.67	1.42	1.53	1.61	0.17
	U 2	1.44	1.54	1.67	1.66	1.58	0.11

Fixation Durations

Because the arrays of individual fixation durations for each participant in each reading often included extreme values (skewed distributions), we report individual fixation durations for each participant in terms of *medians* rather than arithmetic means.

The faculty conductors' median fixation durations were almost identical between the two readings of the Holst excerpt, and were identical in the two Ewazen readings. The graduate conductors' median fixations were also almost identical in the two readings of each piece, but were longer than those of the faculty conductors. Data for the undergraduate conductors were somewhat more varied in terms of median durations. For individual undergraduate conductors, median fixation durations for the two Holst readings (with the metronome and with the recording) were more similar to one another than were the fixation durations in the two Ewazen readings. The undergraduates' median fixation durations were longer than the faculty conductors' but shorter than the graduate conductors' fixation durations.

Table 2.3

Mean Fixation Data for Four Score Readings: Fixation Duration Medians

		Holst Metronome Reading	Holst Audio Reading	Ewazen Metronome Reading	Ewazen Audio Reading	Overall M	Overall SD
Fixation Duration Median (ms)	F 1	300.00	300.00	266.67	266.67	283.34	19.24
	F 2	333.33	366.67	333.33	333.33	341.67	16.67
	G 1	383.33	408.33	433.33	400.00	406.25	20.83
	G 2	333.33	300.00	266.67	300.00	300.00	27.21
	U 1	322.22	333.33	366.67	333.33	338.89	19.25
	U 2	358.33	366.67	316.67	300.00	335.42	32.18

Saccade Direction and Distance

The arrays of individual saccade distances in each reading also included extreme values, and here too we report individual saccade distances in terms of *medians* for each participant rather than arithmetic means. It is also important to note that we calculated saccade distances in terms of horizontal beats.

Table 2.4

Mean Fixation Data for Four Score Readings: Percentage of Progressive Saccades and Saccade Distance Medians

		Holst Metronome Reading	Holst Audio Reading	Ewazen Metronome Reading	Ewazen Audio Reading	Overall M	Overall SD
Percentage Progressive Saccades	F 1	75.36	75.81	60.92	70.42	70.63	6.92
	F 2	69.12	77.94	61.96	67.07	69.02	6.66
	G 1	63.64	69.09	69.70	76.81	69.81	5.40
	G 2	75.00	64.18	67.53	63.77	67.62	5.20
	U 1	77.92	78.69	74.24	76.39	76.81	1.96
	U 2	69.74	77.19	61.33	68.83	69.27	6.49
Saccade Distance Median (beats)	F 1	2.00	3.00	1.00	1.00	1.75	0.96
	F 2	3.00	3.00	1.00	1.00	2.00	1.15
	G 1	3.50	3.00	1.00	1.00	2.13	1.31
	G 2	3.00	2.00	1.00	1.00	1.75	0.96
	U 1	2.00	3.00	1.00	1.00	1.75	0.96
	U 2	2.00	3.00	1.00	1.00	1.75	0.96

Given that we were primarily interested in fixation timing in relation to the ongoing music, we calculated saccade distance only in terms of horizontal beats spanned. Saccade distances were remarkably similar among all participants in all readings, and overall means show that all participants' saccades spanned about 1.5 beats on average. Saccades were slightly longer for all participants during the Holst readings than they were during the Ewazen readings.

During the Holst readings, the graduate participants had the lowest percentages of progressive (moving the eyes forward in the music) saccades (HM: 69.3%; HR: 66.3%). These two participants made frequent vertical saccades; they looked up or down the pages while staying on the same beat of the same measure of the score. During the Ewazen readings, the faculty participants had the lowest percentages of progressive saccades (EM: 61.44%; EA: 68.95%). Similar to the graduates during the Holst readings, the faculty had a large percentage of vertical saccades during the Ewazen readings.

All participants made a few (between 5-8) regressive saccades throughout the four readings. Regressive saccades typically indicate a need to recheck or clarify information, and it is unsurprising that experienced conductors evinced few regressive saccades. Inexperienced music readers typically make more regressive saccades, and although the undergraduates in this study were less experienced than the faculty and graduate students in reading full scores, they were highly experienced music readers.

Though the undergraduates made few regressive saccades, the function of their regressive saccades was different than was the function of the faculty and graduate participants' regressive saccades. When faculty and graduate participants made regressive saccades, it was typically to check instrument names on the left side of the score page. When undergraduates made regressive saccades, they were typically looking at music that had already passed.

Temporal Alignment and Fixation Locations

Temporal Alignment

One striking difference between levels of conductor expertise was in the timing of fixations in relation to the timing of events in the score (Table 2.5). Faculty fixations were almost always ahead of events in the score in both readings of both pieces; only 40 of F1's 289 fixations (~14%) in the four readings were behind the metronome or recording, and only 8 of F2's 310 fixations (~3%) in the four readings were behind. And only 4 of these 48 fixations were more than two beats behind events in the music. All four of those fixations were by F1, who was looking at part names and then immediately returning to the previously fixated music. Both faculty conductors remained ahead of the music by similar numbers of beats during both the Holst and Ewazen readings. F1 tended to stay about one beat ahead of the ongoing music, whereas F2 stayed 2-3 beats ahead.

Table 2.5

Mean Fixation Data for Four Score Readings: Temporal Alignment with Ongoing Music

		Holst Metronome Reading	Holst Audio Reading	Ewazen Metronome Reading	Ewazen Audio Reading	Overall	
						M	SD
Temporal Alignment Median — (+ or - number of beats)	F 1	1.00	1.00	1.00	1.00	1.00	0.00
	F 2	3.00	2.00	3.00	2.00	2.50	0.58
	G 1	2.00	3.25	-2.00	1.00	1.06	2.24
	G 2	2.50	3.00	3.00	3.00	2.88	0.25
	U 1	-0.50	2.00	2.00	2.50	1.50	1.35
	U 2	-14.00	1.00	4.00	1.00	-2.00	8.12

Graduate conductors' fixations were also frequently ahead of the metronome and audio recording, but not as consistently as were those of the faculty. All but 3 of G2's 281 fixations (~1%) were ahead of the music in all four readings, and the fixations that were behind the music were not more than 2 beats behind. A large number of G1's fixations were behind the beat during the EM reading (47 of 66 fixations); however, these fixations were, on average, 1.5 beats behind. It appears that G1 fell slightly behind the metronome at some point, and given that there was no audible cue to indicate whether his imagined music was "in the right place" relative to the metronome, it is likely that this reflects a momentary lapse. Aside from the EM reading, only 24 of G1's 176 fixations in the other three readings were behind (~14%).

The undergraduate conductors tended to fixate locations that were behind the music much more frequently than did the more experienced conductors, especially during the HM reading. The two undergraduates together made 561 fixations across all four readings. Of these, 156 (~28%) were behind the music. Many of these fixations behind the ongoing music occurred during the HM reading, which was also the first reading for all participants. It is important to emphasize again that in this listening condition there was no auditory cue to indicate whether the participant was reading coincident with the ongoing music, and here again consecutive fixations that were consistently behind could have been the result of a momentary timing lapse. This seems to have been the case for U1, whose lagging fixations during the HM reading were consistently 2-3 beats behind the metronome. U2's lagging fixations became progressively farther behind the ongoing music as the HM reading proceeded.

Fixation Locations

We classified fixation locations as either informative or uninformative according to the function of the fixation targets and the timing of the fixations relative to the ongoing music or metronome (Table 2.6). *Informative* fixations were those that occurred ahead of or coincident with the ongoing music and focused on various changes in the music, such as instrument entrances, phrase beginnings, and changes in voicing. Consecutive fixations that progressed along an ongoing musical line were also labeled informative. We labeled as *noninformative* fixations that were behind the ongoing music or metronome and fixations on blank measures, fixations off the score page entirely, and fixations on repeating pitches in an accompaniment line.

Table 2.6

Mean Fixation Data for Four Score Readings: Percent of Informative Fixations

		Holst Metronome Reading	Holst Audio Reading	Ewazen Metronome Reading	Ewazen Audio Reading	Overall M	Overall SD
Percentage of Informative Fixations	F 1	75.36	69.35	80.46	78.87	76.01	4.92
	F 2	82.35	73.53	73.91	70.73	75.13	5.02
	G 1	61.82	60.00	21.21	65.22	52.06	20.68
	G 2	83.82	83.58	76.62	79.71	80.93	3.44
	U 1	41.56	72.13	62.12	69.44	61.31	13.83
	U 2	15.79	73.68	69.33	76.62	58.86	28.87

The greatest difference in informative fixation percentages among the conductor experience categories occurred during the HM reading. Faculty and graduate participants made a higher percentage of informative fixations during that reading than did the undergraduates, largely a result of undergraduates' fixations that were behind the metronome. During the HR reading, the mean percentage of informative fixations was about 72% for all participants. During the Ewazen readings, the faculty participants had the highest percentages of informative fixations. The graduate and undergraduate participants had a higher percentage of informative fixations during the ER reading than they did during the EM reading.

We also identified whether consecutive fixations remained on a single instrument line or switched to different lines (Table 2.7). The faculty conductors changed their fixation targets among different lines of the score more frequently throughout all four readings than did the graduate and undergraduate participants, but the graduate participants switched lines more frequently than did the undergraduates. The undergraduate participants more often followed a single instrument line (usually the trumpet or cornet, which was assigned the melody) than did the faculty and graduate participants, especially during the unfamiliar Ewazen readings. Another interesting result is that both faculty participants and G2 changed lines more frequently during the Ewazen readings than during the Holst readings. Both undergraduate participants changed lines more frequently during the Holst readings (familiar piece) than during the Ewazen readings (unfamiliar piece). G1 changed lines similar numbers of times during all four readings.

Table 2.7

Mean Fixation Data for Four Score Readings: Percent of Line-Change Fixations

		Holst Metronome Reading	Holst Audio Reading	Ewazen Metronome Reading	Ewazen Audio Reading	Overall M	Overall SD
Percentage of Line-Change Fixations	F 1	63.77	62.90	75.86	78.87	70.35	8.20
	F 2	72.06	77.94	80.43	80.49	77.73	3.96
	G 1	54.55	59.62	54.55	55.07	55.95	2.46
	G 2	73.53	73.13	85.71	81.16	78.38	6.12
	U 1	51.95	67.21	42.42	51.39	53.24	10.28
	U 2	55.26	50.88	40.00	45.45	47.90	6.62

Scan Paths

Although patterns of gaze (scan paths) are not readily amenable to statistical analyses, we describe the characteristics of participants' patterns of fixation in relation to the ongoing music (see Appendix A for images of participant scan paths). During both

Holst readings, both faculty conductors frequently fixated the trumpet line (often the melody line) in the middle of the page. They often glanced to other instrument lines to "check in" but tended to return to the trumpet. When focusing away from the trumpet line, faculty typically followed the melody line to other instrument parts (e.g., when the predominant line travels down through the low brass after the key change in the Holst score excerpt, mm. 15-16 of rehearsal letter C). During the Ewazen readings, both faculty conductors frequently fixated the trumpet, alto saxophone, and flute lines, all of which have the melody throughout the excerpt. Faculty conductors also intermittently fixated the clarinet line, which had continuous moving eighth notes during much of the excerpt. Faculty conductors' scan paths were remarkably similar between the metronome and audio readings of each piece (Figure 2.3). Though fixation locations and timing were not identical between each reading, the faculty participants often fixated similar locations at similar points in the score and switched their fixation locations to the same lines at similar times in the metronome and audio readings of each piece, perhaps reflecting their capacity to fully imagine the music while reading with the metronome.

Scan paths of the individual graduate conductors while reading with the metronome and reading with the recording were less similar to one another than were those of the faculty. During the HM reading, G2 tended to fixate the trumpet line (often the melody line) in the middle of the page, but G1 primarily fixated woodwind melody lines, which had an independent voice at rehearsal letter C and then doubled the trumpet line after rehearsal letter D. The graduate conductors glanced to other instrument lines as did the faculty, and they also tended to return to melody lines. Like the faculty, when glancing away from the melody line, graduates typically looked at other pertinent information such as releases, entrances, or phrase beginnings in other parts. During the Ewazen readings, graduates, like the faculty, most often fixated the trumpet, alto saxophone, and flute lines. Graduates also fixated the clarinet line, which had moving eighth notes through much of the excerpt. One graduate confirmed during his interview that he looked for the smaller, moving notes, which was a feature of the clarinet lines.

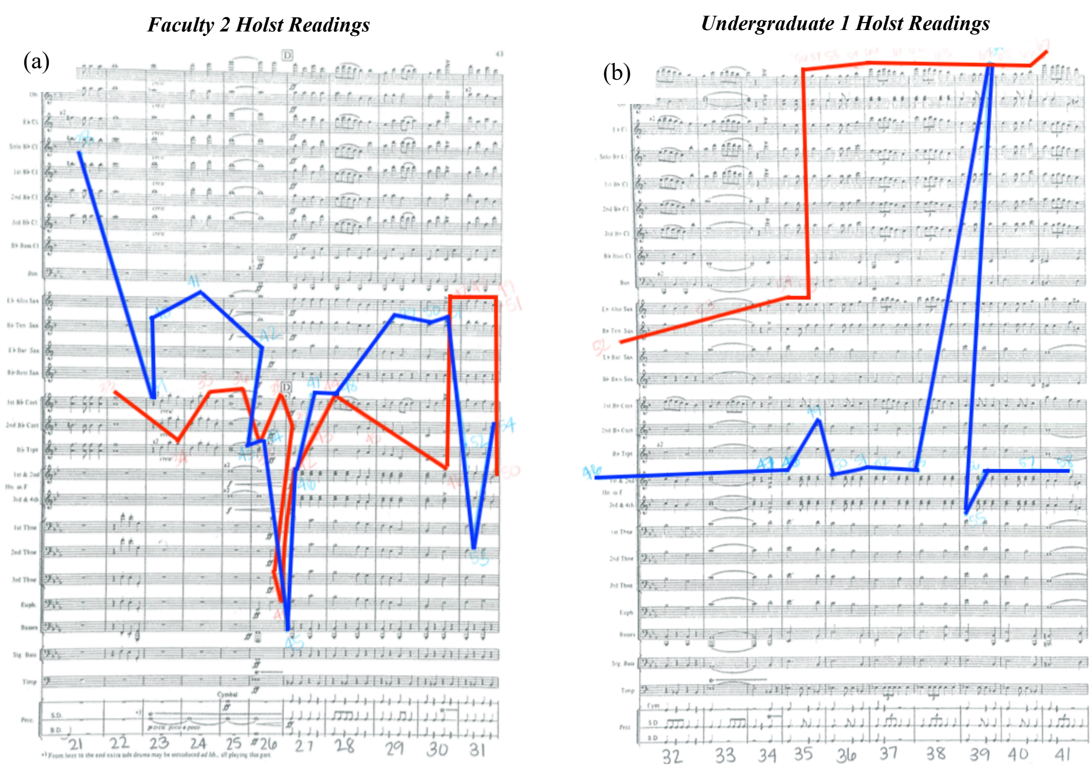


Figure 2.3: Sample scan paths of F2 (a) and U1 (b) during the Holst metronome and Holst audio readings. The printed music scores display the participants scan paths while reading along with the metronome (red lines) and while reading listening to the recording (blue lines).

Scan paths for undergraduates when listening to a metronome and listening to the audio recording were much more *un*alike than were those of the more experienced participants, and there were many differences among the individual undergraduates' gaze behaviors overall. During all four readings, undergraduates primarily fixated melody lines or the lines of the participants' own principal instruments, and many of undergraduates' fixations were at uninformative locations, especially during the HM reading. Although both undergraduates primarily followed the trumpet line throughout the Holst excerpt, their scan paths did not follow the sequence and timing of the music; these same participants infrequently fixated other lines in the score. During both Ewazen readings, undergraduates *in*frequently fixated releases, entrances, and phrase beginnings (what we labeled as informative locations), and in all four readings, undergraduates often fixated empty measures or locations off the score.

Interview Responses

Following each eye tracking session, participants answered interview questions about their score-reading practices: (1) When studying a new score (familiar or unfamiliar), do you ever look straight through the score (without pausing or revisiting certain parts) as we asked you to do today?, (2) During your routine score study, to what elements of the score do you pay the most attention?, (3) Does your attention to certain elements change depending on the number of times you have looked through the score? For example, did you focus on different elements during the second reading of each score?, (4) During the recording without the audio of the music, were you audiating the music in your head?, (5) Is audiating the music a typical part of your score study? What other methods do you use to "hear" the music during score study?, (6) How do you think the recording that did include audio influenced your attention to elements of the score?, (7) Does your attention to certain elements change depending on whether the score you are studying is familiar or unfamiliar? How do you think studying a familiar versus an unfamiliar score influenced your attention to elements of the score?

We asked participants whether the reading tasks they had just completed for the study were similar to components of their typical score study. Three participants (F1, F2, U2) answered that they often quickly scan through a new score before studying the music in depth. The remaining participants (G1, G2, U1) said that they rarely look through the score quickly; they typically pause occasionally for deeper study. Participants answered that they attend to many different elements of the music during score study including part doublings (F1), harmony and unison parts and texture (F1, F2, G2), moving lines with many notes (G1); individual instrument lines (G2, U1, U2), and entrances (U2). The graduate and undergraduate participants listed fewer elements than did the faculty conductors. The undergraduates' responses aligned with their gaze behavior in that these participants had lower percentages of fixation location changes; the undergraduates tended to follow individual instrument lines more often than did faculty and graduate participants.

When asked about how the metronome and audio recordings affected their perceptions of the score, four of the participants answered that they were familiar with the Holst excerpt, so they were able to imagine how the music sounded immediately even without the audio recording (F1, G2, U1, U2). These participants said they felt they could look at more elements of the music in this familiar piece. Four of the six participants mentioned having difficulty imagining how the Ewazen excerpt sounded (F1, G1, and U1) or being afraid of getting lost during those readings (U2). F2 was the only participant who stated that he felt he imagined both pieces successfully. Their perceived familiarity with the Holst score appeared consistent with the gaze behavior of F1, F2, and G2. These three participants stayed ahead of the music, looked at different lines of music, and their scan paths were similar between metronome and audio readings of the Holst score. The perceived difficulty with the Ewazen score also appeared consistent with the gaze behavior of the undergraduate participants. Though they both stayed ahead of the metronome and music, both U1 and U2 tended to follow a single instrument line, likely a strategy to keep pace with the music.

DISCUSSION

We set out to examine the eye movements of faculty, graduate, and undergraduate conductors reading music scores while listening to a metronome and while listening to recordings of the music. Our findings are best described in terms of the theories of visual perception and oculomotor control, specifically the transition during the development of expertise from bottom-up (i.e., salience-driven) to top-down (i.e., goal directed) control of visual fixations (Buschman & Miller, 2007). What perhaps best captures the variations in gaze behavior between non-experts and experts is the difference between *looking at* versus *looking for*.

The current investigation is our first attempt to examine musicians' attention allocation in the context of music reading, and the first study to examine the gaze behavior of musicians studying music scores. Results show that expert conductors approach and think about score reading differently than do less experienced conductors. The elements to which the experienced conductors attended revealed their priorities and thought processes as they approached a familiar and unfamiliar score. The locations and timing of the experienced conductors' fixations demonstrates that their thinking was fundamentally different than that of the novice conductors.

While reading the scores, regardless of condition, the faculty and graduate conductors looked for and fixated informative elements in multiple instrument lines, switching frequently to different music lines while keeping pace with the ongoing music, whether it was heard or imagined. The less-experienced conductors did not change their fixation points to look at different lines as frequently as did the experienced conductors and fell behind the ongoing music more frequently than did the faculty and graduates.

The experiences of the experts have shaped their score-reading behavior in ways that the undergraduates' more limited experiences have not. The faculty and graduate conductors have spent many hours not only studying music scores, but also rehearsing ensembles while reading scores. These experiences have reinforced advantageous approaches to score reading, both in terms of the goals related to understanding music's structure, planning and managing effective rehearsals, and physically conducting an informed and intelligent interpretation of the music. Highly experienced and expert conductors' iterative practice opportunities have led to their knowing *when* to look at *what* in their efforts to accomplish these goals. The data indicate the extent to which the reading of a full ensemble score is a complex, practiced behavior that involves intuitive (nonconscious) gaze decisions that are not typically addressed in the pedagogy of conducting. In fact, although there is much written about how to "study a score" and mark a score, there is little direction for novices in the literature about how to guide reading full ensemble scores that may contain as many as 30 lines of music.

Our most important finding is that conductor experience and expertise were characterized by consistently fixating informative locations in the score in advance of their occurrence in time, typically 2 beats ahead of their occurrence. Nearly all of the faculty and graduate conductors' fixations were ahead of the music during readings of both pieces, with the audio recording and with the metronome. Faculty and graduate conductors' tendency to fixate several beats ahead of the music and the consistency of their fixation locations between the readings with the audio recording and the readings with the metronome may be reflective of their ability to effectively imagine the music even when no audio recording is present. We should note that the graduate conductors' fixations varied somewhat more than the faculty conductors' between readings with the metronome and readings with the recording of the music. The faculty and graduate conductors also switch their fixation targets among different lines of the score much more frequently than did the undergraduate conductors, perhaps indicating their ability to consciously attend to and keep up with the multiple lines of music.

The two undergraduates fell behind the metronome in the HM reading, and one undergraduate participant seemed to have gotten lost entirely. The undergraduates mentioned during their interviews that because they were familiar with the Holst, they were interested in looking at different elements in the score, but doing so led to their not keeping pace with the ongoing music. Undergraduates did not get as far behind the music during the Ewazen readings and they had in the Holst readings. Their shorter median fixation durations and their interview responses together suggest that undergraduate participants were not actually attempting to imagine the music, but rather were simply trying to keep pace with the music as it unfolded. These results emphasize the idea that faculty and graduate conductors were *looking for* specific things when reading the scores. Undergraduates, by contrast, often appeared to be *looking at* the music as they followed an individual instrument line, fixated informative elements less frequently than did the more experienced participants, or fell behind the metronome or recording.

Nearly all of the faculty and graduate conductors' saccades were progressive in all four readings, a result that is consistent with the findings of previous research in text reading, which indicate that skilled readers typically make more progressive saccades than do novices (Hyona, 1995; Just & Carpenter, 1980). Being experienced music readers, the undergraduate participants also made few regressive saccades during all four readings of the scores, but their regressive saccades revealed differences in their thinking about the ongoing music. The faculty and graduates' few regressive saccades were typically to fixate part names, indicating that these participants were checking which instrument was playing which line rather than rechecking musical content. Undergraduates' regressive saccades, in contrast, most often led to fixations on musical events from instrument lines that had already occurred. The targets of these regressive saccades indicate that the undergraduate students wanted to recheck or clarify music that had already transpired. Rechecking this content took priority over continuing forward in time with the music.

All participants tended to stay closer to the beat, and thus made shorter saccades, during the Ewazen readings than during the Holst readings. Because the Ewazen was unfamiliar and thus more unpredictable, and perhaps because of working memory limitations, participants may have been unable to look too far ahead and still return to the point of the ongoing music without losing their place. Several participants mentioned during their post-reading interviews that they were afraid of getting lost during the Ewazen readings and that they were focused on staying with the music. No participants specifically mentioned fixating notes closer to the pulse of the music in the Ewazen readings, but this seems like an understandable result of uncertainty while reading unfamiliar music.

It is interesting to consider why a conductor would look ahead of the metronome or recording during score reading. One possibility is that looking ahead during music reading, whether silently reading or physically performing the music, is indicative of cognitive processing. A central feature of music is that it almost always occurs in metered time. The eyes must look ahead of the point of performance or processing in order to obtain upcoming information so that the music can continue in time. If the eyes were to only move to the next portion of music once the currently fixated portion ended, there would naturally be hitches in the continuity of the music whether performed or imagined. This "look-ahead" behavior also occurs in text-reading. Readers look ahead of the point of comprehension (reading silently) or verbalization (reading aloud) in order to process the meanings of full sentences rather than individual words. Though reading does not necessarily occur in metered time like music, a reader still must keep several words in working memory in order to grasp the meaning of the text (Buswell, 1921; Just & Carpenter, 1980; Rayner, 1998; Silva et al., 2016).

The distance of sequential saccades is also an interesting aspect to consider. Evidence from music-reading research indicates that during music performance, experienced readers make larger saccades than do inexperienced readers, and that saccade distance is affected by the complexity of the printed music (Goolsby 1994a; Weaver, 1943). Saccade distance may be an indication of the size of the musical unit or chunk being processed during each fixation. All participants in the current study were experienced music readers, and saccade distance did not vary by expertise level. But saccade distances tended to be shorter during the Ewazen readings, likely a result of the complexity and unfamiliarity of the excerpt.

Considering each gaze measure in isolation does not present the full picture of participants' score reading behavior, and it is important to note the interdependence of several of the measures reported above. When multiple measures are considered in concert, important differences emerge among the participants that seem related to their respective levels of experience and expertise. The faculty participants consistently fixated informative locations of the score, including many different lines of the score, and were able to do so in advance of the events' occurrences in time. The faculty and graduate conductors appear to have a practiced routine of how they approach a score, whether novel or familiar, and they used that routine through each reading.

The experienced participants' facility in reading full scores afforded them time to fixate different lines of music in time with or ahead of the ongoing music. The undergraduates, in contrast, tended to fixate different lines of music less frequently than did the more-experienced participants. Given that the undergraduate participants did not fall behind the ongoing music during the Ewazen reading, it seems that keeping pace required them to primarily fixate a single instrument line without shifting their gaze to other parts in the score.

According to many of the individual measures we report in this study, the gaze behavior of undergraduates was in many ways quite similar to that of the experienced conductors. Yet, there are important observations that reveal differences between score reading among novices and more experienced conductors.

The scan paths and the extent to which participants switched fixations among multiple lines in the score may be an indication of the extent to which the conductors conceive of the full music texture of the entire piece. It is evident that musicians who are highly experienced in reading single-line music for wind instruments, which is the case with all six of our participants, are challenged by reading music that includes multiple voices in the texture. This challenge is perhaps most evident in music schools when undergraduates are tasked with developing piano skills, reading multiple staves simultaneously. But the gaze behavior in the current study may be reflective of something even more fundamental, namely, the ways in which musicians construe the music they listen to and perform. In the case of the participants in this project, the undergraduates may conceive of the music they read as multiple, separate lines of activity that occur together in time, whereas the more experienced conductors may conceive of the music quite differently: as a composite texture with multiple components that are tightly woven together.

This preliminary study of instrumental score reading has important limitations, of course. We studied the gaze behavior of only six participants, all of whom completed four reading episodes of brief music excerpts that were presented in the same order. Additionally, participants were in an unfamiliar environment and wearing eye-tracking gear. These unfamiliar conditions may have affected the participants' gaze behavior.

More research is needed to determine the generalizability of the results obtained in the current project, but it seems clear that the experienced conductors' score reading differed from that of the novices. The experienced conductors were able to acquire useful and timely information as the music unfolded, whether the sound of the music was present or only imagined. The present study provides new information about conductors' visual attention and thinking during score reading and may offer new insights into the differences between expert and novice musical understanding.

Chapter III: Skilled Musicians' Gaze While Observing Music and Nonmusic Performers

To observe expert music teachers working with their students is to witness a seamless weaving together of deep knowledge, virtuosic skill, penetrating insight, and lucid and cogent communication. Experts' decision-making combines (1) a rich memory store that encompasses a range of relevant past experiences that illuminate important relationships among the variables at play in music performance, with (2) keen auditory and visual perception that accurately capture the behavior, and by inference the thinking and feeling, of students.

It is not uncommon to observe a skillful artist-teacher in a master class hear a student perform for the first time and notice some small, almost imperceptible, detail about the student's technique that had gone unobserved by the student and her teacher. By redirecting the student's attention, the artist-teacher fundamentally alters the student's subsequent performance in a way that seems extraordinary to those in attendance. The question of how experts allocate their attention such that they see and hear the fine details of students' music making remains unanswered.

REVIEW OF LITERATURE

Expertise

Many researchers have studied expertise in various domains, including teaching, in an attempt to identify the features that characterize the thinking and behavior of experts (Berliner, 1986, 1988, 2001, 2004; Carter et al., 1988; Ericsson, 2008; Ericsson et al., 1993; Madsen et al., 1992). The variables that determine whether a teacher is labeled an expert are not well defined in the education literature and have been the source of unsettled arguments for many decades (Bereiter & Scardamalia, 1993, p. 11; Berliner, 1986, 2001; Bilalić, 2018, p. 2-5; Gobet, 2016, p. 1-6). Defining teachers as experts most often is determined by examining records of student accomplishment (e.g., in music, winning competitions and auditions for professional employment) and recommendations from knowledgeable colleagues (e.g., Carter et al., 1988; Colprit, 2000; Duke & Simmons, 2006; Goolsby 1997, 1999; Juchniewicz, Kelly, & Acklin, 2014; Millican, 2013; Sogin & Wang, 2002; Standley & Madsen, 1991; Worthy & Thompson, 2009), but less often by documenting what teachers actually do in their efforts to bring about meaningful changes in student performance.

Of course, time and experience contribute to expertise, as most experts have invested thousands of hours and have accumulated innumerable experiences working in their respective domains (Berliner, 1986, 1994, 2001; Ericsson, 2008; Ericsson et al., 1993; Goolsby, 1996; Hogan & Rabinowitz, 2009; Hogan, Rabonowitz, & Cravan, 2003; van den Bogert, van Bruggen, Kostons, & Jochems, 2014). But there are many individuals who invest similar time and effort who nevertheless fail to become experts according to any criteria (Ericsson, 2008; Ericsson et al., 1993; Standley & Madsen, 1991). The mere passage of time in service is not determinative of expertise.

Standley and Madsen (1991) created a procedure to test the observation capabilities of expert and nonexpert teachers, the latter category including experienced teachers and novices. Participants observed an uninterrupted series of short video recordings of musical events, including rehearsals, classes, lessons, and performances, and wrote about what they saw. Their responses were then classified according to factual accuracy (describing what was seen and heard) and inferential accuracy (e.g., describing intentions, causal relationships, and goals). Teachers identified as experts scored significantly higher than nonexperts in the accuracy of their observations, and, as might be expected, experienced nonexpert teachers scored significantly higher than did novices. The data reflect the fact that experts *noticed more* than nonexperts in the brief time they had to observe each video and were able to see more deeply into what they saw, as evidenced by their accurate inferential statements.

Research has demonstrated that expertise in every domain of endeavor embodies a suite of important features, only one of which is the accumulation of extensive experience. Experts possess extensive knowledge about their disciplines that is readily accessible (Berliner, 2001, 2004; Bilalić, 2018; Carter et al., 1988; Covino & Iwanicki, 1996; Duke & Simmons, 2006; Gobet, 2016; Hogan et al., 2003; Hogan & Rabinowitz, 2009; van den Bogert et al., 2014), and expert memory is *organized* in ways that connect details to fundamental underlying principles that serve as the structural basis for retrieval, insight, problem solving, and creativity (Bilalić, 2018; Chase & Simon, 1973; Ericsson & Kintsch, 2000; Gobet, 2016; Gobet & Simon, 1998). The fundamental concepts of an expert's discipline are linked together through networks of memories that have been strengthened over years of activation and retrieval. Repeated acts of retrieval and application increases the profusion of interconnections among memories, thereby increasing the accessibility of memories and revealing relationships that may at first be obscure (Bilalić, 2018; Feigenbaum & Simon, 1984; Gobet, 2016; Richman, Staszewski, & Simon, 1995).

Experts' extensive domain knowledge facilitates their recognizing patterns in new stimuli and making accurate predictions about future events (Bergee, 2005; Berliner, 2001; Bilalić, 2018; Bilalić, Langner, Erb, & Grodd, 2010; van den Bogert et al., 2014). Presented with an array of new information, experts quickly recognize important features and connect essential elements to previously stored knowledge. An expert teacher entering a classroom of new students, for example, can readily make insightful predictions about how instruction is likely to proceed and how students will likely respond to planned activities. Recognizing patterns that resemble previous experiences informs accurate predictions that lead to effective decision making.

Experts also have extremely clear *intentions* about what should take place in a learning experience and equally clear short- and long-term goals (Bergee, 2005; Bilalić, 2018; Duke & Simmons, 2006; Hogan et al., 2003; Millican, 2013; Worthy & Thompson, 2009). These mental representations are facilitated by experts' domain knowledge and pattern recognition. Experts' internal models of effective learning sequences also enhance their ability to identify discrepancies between these clear intentions and what actually transpires. A choir teacher who has a strong auditory image of a piece she is rehearsing and the steps in the rehearsal to bring her instructional goals to fruition possesses a template with which to assess progress throughout the course of instruction.

Developing a better understanding of the perception and thinking of experts may contribute to the development of teaching skills among novices (Bereiter & Scardamalia, 1993), though documenting and describing the observable behaviors of experts is but one element in the process. A full understanding of expertise requires information (currently unavailable) about moment-to-moment attention allocation and decision making, enabling access to elements of thinking and behavior that may operate below experts' conscious awareness (Bilalić, 2018; Gobet, 2016; for a review, see Gobet et al., 2004).

Eye Movements as a Window into Perception and Cognition

It is by now well documented that when and where the eyes move are indicators of cognitive attention (Buschman & Miller, 2010; Corbetta et al., 1998; Corbetta & Shulman, 2002; Kowler et al., 1995; Orquin & Mueller Loose, 2013; Yarbus, 1965), and numerous investigations have demonstrated the utility of recording eye movements as a way to better understand the thinking and decision making of individuals, including experts (Corbetta et al., 1998; Kowler et al., 1995; Orquin & Mueller Loose, 2013). Experts often perceive and process new information and unfamiliar scenes faster than do novices. They quickly discern the relationships between novel experiences and previous experiences stored in memory, and when presented with a new scene, make their first fixations more quickly that do nonexperts (Bilalić, 2018; Bilalić et al., 2010; Corbetta & Shulman, 2002; Orquin & Mueller Loose, 2013). This connection to previously-stored knowledge is facilitated by the recognition of patterns in stimuli and by the rewards obtained in previous experiences. In music-reading studies, for example, experts are quicker and more accurate than are novices in noticing visual differences between two lines of music (Drai-Zerbib & Baccino, 2014; Waters & Underwood, 1998; Waters et al., 1997).

Experts are not only quicker than novices in perceiving new information, but they also fixate targets that are most relevant to accomplishing goals. When searching for a target in a visual scene, experts search the most relevant locations and fixate more frequently than nonexperts on task-relevant targets (Bilalić, 2018; Bilalić et al., 2010; Haider & Frensch, 1999; Marcum & Duke, 2017). Expert radiologists, for example, identify lesions on lung x-rays more quickly and with fewer fixations than do novices. Efficiency and speed are facilitated by their tending to fixate only locations that are likely to be informative. Nonexpert radiologists tend to search less purposefully, fixating areas where lesions are unlikely to develop. Because expert radiologists have learned through experience where lesions are most likely to be, they optimize their search by prioritizing visual targets that are the most promising (Donovan & Litchfield, 2013; Kundel et al., 2007). Similarly, when expert and novice chess players are asked to locate pieces (e.g., a rook or a knight) on a chess board with a game in progress, experts find the target pieces quicker than do novices and search only the areas on the board where the target pieces are most likely to be (Bilalić et al., 2010; Reingold, Charness, Pomplun, & Stampe, 2001).

Studies of expert eye movements have revealed that experts perceive visual information fundamentally differently than do novices, because experts absorb more information in a single fixation. Experts' domain knowledge and experience result in their *chunking* information, recognizing patterns that include multiple elements, thus acquiring more information in a single glance. Experts can often process information, initiate action, and accomplish a goal with fewer fixations than would be required for nonexperts. Expert chess players shown pictures of a games in progress, for example, can assess the current state of play and provide advantageous next-moves more quickly and accurately than can nonexperts (Bilalić et al., 2009; Gobet & Simon, 1996).

Expert musicians also chunk information and easily recognize patterns in printed music. Expert music readers make fewer fixations than do novices, fixating familiar and predictable note *groupings* that facilitate speed of processing. Studies of the relationship between reading and performance reveal that experts tend to fixate points in the music that are consistently ahead of where they are actually performing (called *perceptual span*) (Arthur et al., 2016; Burman & Booth, 2009; Buswell, 1921; Cara & Gomez, 2016; Goolsby, 1994b; Hoppe et al., 2014; Penttinen et al., 2013; Rayner, 1998; Rayner & Pollatsek, 1997; Silva & Castro, 2018; Silva et al., 2016). Arthur, Khuu, and Blom (2016) illustrated experts' dependence on recognition of familiar structures by presenting notation that did not follow the conventions of notating music in common-practice Western music (e.g., broken note beams, barlines out of place, and inconsistent spacing of note heads). Experts' performances were negatively affected by these alterations, whereas novices' were not, as novices were reading individual pitches rather than recognizing note groupings.

Experts in nearly every domain have a clear idea of what information they need to obtain from a scene, given their vivid mental representations of what they expect and intend in a given situation. The gaze patterns of novices, though they often look at the same places that experts look, are not driven by similar clear intentions, expectations, and goals. In terms of visual perception, experts are *looking for* something specific whereas novices are simply *looking at* the various items in the environment.

Perceptual Acuity of Expert Music Teachers

Nearly all of the research in music to date has been devoted to studies of music-reading (Arthur et al., 2016; Burman & Booth, 2009; Cara & Gomez, 2016; Drai-Zerbib & Baccino, 2014; Furneaux & Land, 1999; Gilman & Underwood, 2003; Goolsby 1989, 1994a, 1994b; Hoppe et al., 2014; Kinsler & Carpenter, 1995; Madell & Héébert, 2008; Penttinen et al., 2013; Rayner & Pollatsek, 1997; Silva & Castro, 2018; Sloboda, 1974; Truitt et al., 1997; Waters & Underwood, 1998; Waters et al., 1997; Weaver 1943).

The purpose of this study is to extend the work of Marcum and Duke to include wind instrumentalists with different levels of expertise. We sought to determine differences in gaze behavior among expert, graduate-student, and undergraduate-student flute teachers as they watched individuals performing on woodwind instruments (i.e., flute, clarinet, and alto saxophone) and performing other, nonmusic skills (i.e., juggling, batting practice, and ballet).

The observation task was designed to examine differences in gaze behavior among different visual stimuli that included flute playing, other wind instrument playing, and other physical activities unrelated to music. These stimuli allowed for comparisons among individuals and among tasks.

METHOD

Participants and Procedures

Participants were five female flautists with different levels of performance and teaching experience. The faculty participant (Faculty 1 – F1) was an artist-teacher who had more than 40 years of flute-performance experience and 30 years of flute-teaching experience. Two graduate flute performance students who had teaching responsibilities (Graduate 1 & 2 – G1 & G2), and two undergraduate flute students majoring in music education (Undergraduate 1 & 2 – U1 & U2) also participated. G1 had 15 years of performance experience and approximately 6 years of flute-teaching experience; G2 had 16 years of performance experience and 9 years of flute-teaching experience. U1 had 10 years of performance experience and approximately 2 years of flute-teaching experience in limited contexts, and U2 had 9 years of performance experience and approximately 1 year of flute-teaching experience in limited contexts.

All procedures were approved by the Institutional Review Board for human subjects research at The University of Texas at Austin. The participants gave informed consent and received no compensation for participation. Participants completed the eye-tracking session at a time convenient to their schedules in a classroom on the university campus, and each session lasted approximately 30 minutes. Participants donned Pupil Labs™ eye-tracking glasses, and the primary author adjusted and calibrated the cameras that monitor the position of the eyes and a forward-facing camera that records the visual scene from the perspective of the participant. After adjusting the glasses, Pupil Labs™ Capture software was initiated to begin recording the session.

Table 3.1

Video Clip Descriptions and Durations in Order of Presentation

Video Clip	Clip Duration (s)
Juggling	30
Clarinet 1	19
Saxophone 1	17
Baseball	30
Flute 1	19
Saxophone 2	19
Ballet	28
Clarinet 2	19
Flute 2	18
Flute 1, 2nd Viewing	19
Flute 2, 2nd Viewing	18

Participants initially watched nine video clips of individuals engaged in musical and nonmusical tasks (Table 3.1). Six video clips showed individuals performing a simple melody on woodwind instruments (flute, clarinet, and saxophone; one video per instrument with legato articulation and one video with slurred articulation) and three video clips showed individuals performing nonmusical tasks (juggling, baseball batting practice, and ballet dancing). The two flute videos showed the entire instrument and the upper torso, face, and both hands of the performers. The clarinet and saxophone videos showed the entire instrument, face, both hands and entire torso from the waist up of the performers. The juggling video showed the performer from the knees up including both hands and the performer's face. The baseball and ballet videos showed the full body of both performers. The baseball player remained stationary except for the batting motion, and the ballerina moved across the stage during the clip (see Appendix B for screenshots from video clips). All participants had limited experience with the nonmusical skills shown in the videos clips, and none of the participants had performed those skills themselves.

Videos were projected onto a large screen and sound was played from high-quality speakers on either side of the projector screen. Participants stood 6 ft away from the screen for the duration of the session. Participants were told to watch each video clip and during each video, think of three things each performer could do to improve his or her performance. A black slide preceded each video clip for a length of 5s. Once the participants watched the nine video clips, they re-watched the clips of the two flute players, because flute was the participants' area of experience. After viewing each flute clip, the participants verbally answered the question, "What three suggestions would you give this individual to improve his/her performance?" After the participant gave three suggestions, each was asked whether there was anything else they noticed about the performer or performance. Participants were not asked to share their suggestions for the other performers in the videos.

After the eye-tracking session concluded, participants answered questions about their typical goals and attentional focus when watching new students perform: (1) When you see and hear a student play this instrument (flute) for the very first time, what do you typically pay attention to? What are the most important features of a new student's performance that you look and listen for? Do your priorities about what to look and listen for change with the age and experience level of the student, or do you always look and listen for the same things?, (2) You gave three suggestions for improvement after each flute clip. Can you tell me how what you saw and what you heard contributed to your decisions about suggestions for improvement? Do you think you gathered more information to make those decisions from watching the performer or listening to the performer?, (3) Please describe your experience with juggling, dancing, and baseball (Have you ever performed these activities, have your regularly watched someone else performing these activities, have you taught these activities)?, (4) Please describe your experience playing and teaching your primary instrument. How long and in what contexts have you played and taught your instrument?

Data Analysis

The gaze analysis software merges data from the eye and scene cameras to create a video of scan paths of participants' eye movements that are superimposed over the scene (which in this case shows the video clips of performers) (Figure 3.1). Thus, it is possible to observe the location and timing of each saccade and fixation in relation to the ongoing performance.

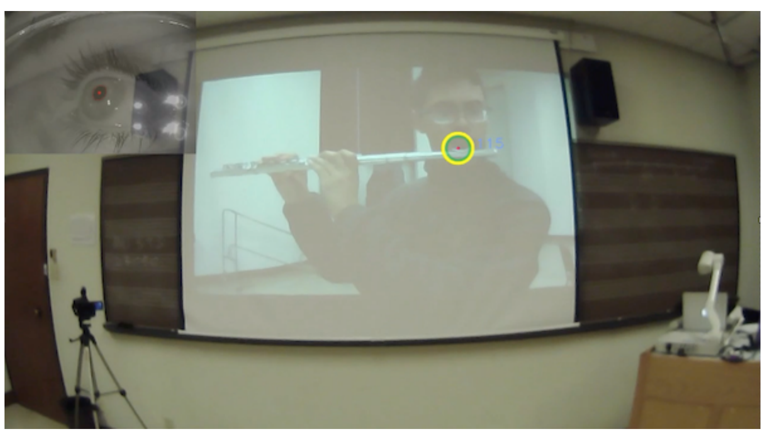


Figure 3.1: Screenshot of composite video showing the participant's eye and the scene. The green circle and red dot indicate the participant's current gaze position, and the yellow circle indicates a fixation at that location.

We calculated fixations as video frames in which the eye moved slower than 40 degrees per second of velocity. In most contexts, human perception of a visual stimulus requires a fixation of at least 150 ms in duration. After setting velocity parameters, we set the range for analyzing fixations to 200-4000 ms.

We coded each fixation according to its video clip and location in the scene. For each clip, we calculated mean fixation duration, fixation frequency, location and duration of the first fixation on the performer. The durations of the clips varied, so we calculated fixation frequency as fixations per seconds (fps) in order to compare fixation frequencies across clips. We grouped fixations by location and determined the total duration participants spent on each individual target of each performer (e.g., embouchure, right-hand fingers). We also gathered data about participant scan paths and gaze behavior from watching their videos, and we compared the quantitative data with the qualitative data gathered from watching the video clips.

RESULTS

The measures of data we report, which include frequencies and durations of fixations, narrative descriptions of scan paths (i.e., participants' fixation targets), and participant interview responses, demonstrate that participant gaze behavior varied by level of expertise (Table 3.2). The gaze behavior of the artist-teacher was different than that of the other participants, although G1's gaze behavior resembled the gaze behavior of the artist-teacher much more so than did G2's, whose gaze behavior was more like that of the two undergraduates. We present the results below with this in mind. In light of our sample size, we include only descriptive statistics in our analysis.

Table 3.2

Mean Fixation Data for Video Viewings: Duration Means, Rate, Mean Number of Targets Fixated, Mean Duration of First Fixation, Number of Target Changes in First Ten Seconds

Measure	Participant	Video Clip			
		Flute Only	*Clarinet/ Alto Sax*	*Non-Music*	*Overall*
Mean Fixation Duration (ms)	*F 1*	996.42	883.37	707.62	876.54
	G 1	1225.82	699.87	412.13	812.65
	G 2	494.52	529.07	557.96	524.39
	U 1	470.37	464.17	533.18	485.25
	U 2	705.60	781.38	783.51	754.40
	Overall	778.55	671.57	598.88	690.64
Mean Fixations per second	*F 1*	0.91	1.10	0.86	0.97
	G 1	0.88	1.24	1.19	1.10
	G 2	1.15	1.37	1.06	1.21
	U 1	1.39	1.49	0.96	1.31
	U 2	1.22	1.11	0.75	1.05
	Overall	1.11	1.26	0.96	1.13
Mean Number of targets fixated	*F 1*	6.00	8.00	5.00	6.00
	G 1	5.50	6.75	5.33	5.91
	G 2	7.50	9.25	7.33	8.09
	U 1	8.75	8.50	5.33	7.73
	U 2	9.50	8.25	7.00	8.36
	Overall	7.45	8.15	6.00	7.22
Mean Duration of first fixation (ms)	*F 1*	1691.67	1050.00	888.89	1239.39
	G 1	808.33	691.67	433.33	663.64
	G 2	508.34	408.33	644.45	509.09
	U 1	241.92	483.34	711.11	457.67
	U 2	616.67	808.34	488.89	651.52
	Overall	773.38	688.33	633.33	704.26
# of Target Changes in First 10 s of Clip	*F 1*	6.25	11.30	12.70	9.82
	G 1	8.25	11.30	15.30	11.30
	G 2	11.80	17.80	13.00	14.30
	U 1	17.80	13.50	18.30	16.40
	U 2	13.00	14.50	10.70	12.90
	Overall	11.40	13.65	14.00	12.93

All five participants fixated several similar targets when viewing the flute videos, but the artist-teacher and one graduate participant, G1, tended to fixate fewer targets for longer durations than did G2 and the undergraduate participants. For example, all participants fixated the embouchures and fingers of each flute performer. The artist-teacher and G1 spent the majority of fixation time on those two targets, whereas the undergraduate participants also frequently fixated the flute performer's eyes, shoulders, chest, instrument, and other items in the scene other than the performer. G2, like the artist-teacher and G1, most frequently fixated the embouchure and fingers of each performer, but like the undergraduates, she also fixated items in the scene other than the performer. F1 and G1 often fixated targets for longer durations before moving to the next target, whereas G2 and the undergraduate participants quickly skipped among fixation targets without lingering on any one location.

F1 and G1 Participant Results

The artist-teacher's (F1) and one graduate participant's (G1) gaze behavior was remarkably consistent, both within their own data across the different categories of video clips and in comparisons with each other (Table 3.3). F1 and G1 fixated a similar number of targets in each clip, and fixations frequencies were similar across clips. Both participants' fixations were longer during flute clips than they were during clarinet, saxophone, and nonmusic clips.

Table 3.3

F1 and G1 Mean Fixation Data for Video Viewings: Duration Mean, Rate, Number of Targets Fixated, Mean Duration of First Fixation, Number of Target Changes in First 10 Seconds of Each Stimulus

Video Clip	**Participant**	**Mean Duration (ms)**	**# of Target Changes in First 10s**	**Fixations per second (fps)**	**Number of Targets Fixated**	**Duration of First Fixation (ms)**	**Location of First Fixation**
Juggling	F1	708.97	12	0.87	6	533.33	Face
	G1	554.84	13	1.03	3	466.67	Face
Ballet	F1	508.33	8	1.07	7	1400.00	Face
	G1	379.17	8	1.14	5	333.33	Face
Baseball	F1	905.56	18	0.64	2	733.33	Face
	G1	302.38	18	1.40	8	500.00	Face
Clarinet 1	F1	592.59	16	1.42	9	1166.67	Embouchure
	G1	449.02	16	1.74	8	300.00	Eyes
Clarinet 2	F1	632.55	9	1.37	12	500.00	Embouchure
	G1	709.09	9	1.16	7	1266.67	Embouchure
Sax 1	F1	972.92	10	0.94	5	600.00	Embouchure
	G1	864.71	10	1.00	7	300.00	Embouchure
Sax 2	F1	1335.90	10	0.68	6	1933.33	Embouchure
	G1	776.67	10	1.05	5	900.00	Embouchure
Flute 1	F1	1180.00	5	0.79	5	466.67	Embouchure
	G1	845.61	11	1.00	8	233.33	Eyes
Flute 2	F1	830.00	8	1.11	6	3966.67	Embouchure
	G1	796.49	10	1.06	7	200.00	Embouchure
Flute 1 2nd View	F1	1107.14	6	0.74	7	1933.33	Embouchure
	G1	2509.52	3	0.37	3	1900.00	Embouchure
Flute 2 2nd View	F1	868.52	6	1.00	4	400.00	Embouchure
	G1	751.67	9	1.11	4	900.00	Embouchure
Overall	F1	876.54	9.82	0.97	6.0	1239.39	
	G1	812.65	11.30	1.10	5.91	663.64	
Nonmusic Clips	F1	707.62	12.70	0.86	5.0	888.89	
	G1	412.13	15.30	1.19	5.33	433.33	
Cl/Sax Clips	F1	883.37	11.30	1.10	8.0	1050.00	
	G1	699.87	11.30	1.24	6.75	691.67	
Flute Clips	F1	996.42	6.25	0.91	6.0	1691.67	
	G1	1225.82	8.25	0.88	5.50	808.33	

Previous research has shown that experts' first fixations in a new scene tend to last longer than do novices' (see Gegenfurtner, 2011 for a review). When F1 and G1 watched the video clips of woodwind performers, 14 of their 16 initial fixations were on the embouchure of the performer, and these initial fixations lasted between 200-3966 ms. (G1 first fixated the eyes of the performers only during the first clarinet and first flute videos.) During the three video clips of nonmusic performers, F1's and G1's six initial fixations were on the faces of the performer, and these fixations lasted between 333-1400 ms. F1 spent the greatest percentage of total fixation time during all four flute video clips fixating the embouchure of the performer (Flute 1 Clip: 71%; Flute 2 Clip: 55%; Flute 1 Clip 2nd Viewing: 58%; Flute 2 Clip 2nd Viewing: 38%), clearly a central element of quality flute performance. G1 also spent the greatest percentage of total fixation time during all four flute videos fixating the embouchure of the performer (Flute 1 Clip: 47%; Flute 2 Clip: 59%; Flute 1 Clip 2nd Viewing: 84%; Flute 2 Clip 2nd Viewing: 69%).

We observed how many times participants changed the target of their fixations during the first 10 seconds of each video clip. F1 appeared to have a clear idea of what she was looking for and what she wanted to see. Not only were F1's initial fixations longer than other participants' (including G1), F1 switched fixation targets fewer times during the first 10 seconds of each video than did other participants (M = 9.82 target changes over all video clips; M = 6.25 target changes during flute video clips). Like F1, G1 switched fixation targets fewer times than did the other graduate and undergraduate participants (M = 11.30 target changes over all video clips; M = 8.25 target changes during flute video clips).

We included among the stimulus presentations videos of performers demonstrating skills that were similar to the participants' area of flute expertise (clarinet and saxophone) and outside of the participants' expertise (nonmusic performances of juggling, baseball, and ballet). During the clarinet and saxophone videos, similar to when she watched the flute videos, F1 spent the greatest percentage of fixation time on the performers' embouchures. G1 also spent the greatest percentage of fixation time on the performers' embouchures except during the first saxophone video (in this video, G1 spent the greatest percentage of fixation time on the performer's instrument, perhaps an indication that she was listening to the sound of the performance rather than looking for visual cues). Though not clarinet or saxophone experts, F1 and G1 are accomplished music teachers, and their attention was drawn to the embouchure of the performers, similar to when they each watched the flute players. F1 and G1 fixated the greatest number of targets during these videos compared to the flute and nonmusic videos, and they both changed their fixation targets more frequently during the first 10 s of these videos than they did during the flute videos. Based on these data, their attention did not appear to be as focused on a few specific targets while watching the clarinet and saxophone players.

During the nonmusic clips, F1 and G1 spent the greatest percentages of fixation time looking at performers' faces. Research suggests that observers viewing scenes that include people typically fixate faces if there are no other task goals (Bindemann, Burton, & Jenkins, 2005; Birmingham, Bischof, & Kingstone, 2008; Birmingham, Bischof, & Kingstone, 2009; Fletcher-Watson, Findlay, Leekam, & Benson, 2008; Freeth, Chapman, Ropar, & Mitchell, 2010; Ro, Russell, & Lavie, 2001; Rösler, End, & Gamer, 2017; Smith & Mital, 2013; Suda & Kitazawa, 2015; Theeuwes & Stigchel, 2006; & Vuilleumier, 2000). These two participants' fixations were consistent with this tendency, even though they had been given instructions to think of three suggestions to improve the performances they observed. Their lack of experience and expertise in these areas resulted in their looking at the performers' faces rather than targets relevant to the task.

After viewing all nine music and nonmusic videos once, each participant watched the two flute performances again. After viewing each flute clip for the second time, F1 and G1 gave suggestions for performance improvement, and these suggestions featured areas on the performer that each participant also fixated during the videos. F1 suggested that the performer in the Flute 1 video lower the right hand for a more natural playing position and decrease tension in the neck. She also mentioned that the performer had a "nice contact point" of the flute on the chin and kept his fingers close to the keys with a "nice hand position." G1 gave different suggestions than did F1 for the first flute performer. She suggested that the first performer reposition the flute on the face to be lower beneath the bottom lip and that the performer direct his air farther downward. She noted that the performer "did not always set his embouchure and instrument properly after breathing," and advised that he "reset carefully after each breath." When asked if she noticed anything else about the performance, G1 said that the performer's articulation was "rough" and that the tone seemed "overblown and spread."

After watching the second performer (Flute 2 video), F1 noted that the right thumb was jutting forward slightly. She also noted that the performer's face and eyes were neutral, which she interpreted as an indication of "a neutral air flow." She suggested that this performer take a breath that would "enliven the face." She mentioned that this performer had a "nice and stable hand position" and that his embouchure was excellent.

G1 suggested that the second performer use slightly faster air and “support the air more to steady the sound.” She also suggested that the performer slur the excerpt instead of articulating, and noticed that every time the performer rearticulated a note, he also lifted and replaced his finger, an extraneous motion. When asked if she noticed anything else about the performance, G1 answered that she thought the angle of his head joint might be “a little off,” and that the combination of the incorrect angle and the lack of air speed were probably contributing to his quality of tone. Many of G1’s comments pertained to targets that were fixated while viewing the video, although G1 made few comments about the performers’ fingers even though she had fixated the fingers often when she watched the clip.

During the post-eye-tracking interview, F1 answered that when watching new students perform for the first time, she typically pays attention to “whole body fluidity with the instrument (especially lower body)” and instrument stability, and that air pressure and speed also “inform the performance.” F1 stated that “fundamental set up and concepts are always at the forefront until the finishing level.” G1 answered that when watching new students perform for the first time, she typically pays the most attention to embouchure, including the flute placement on the face and the size of the aperture. She said she listens for air speed and air quality, noting whether the sound is spread or if the performer frequently drops the pitch an octave. G1 said she also typically looks at the hands and body position, but mostly focuses her attention on the embouchure of a new student. When asked whether she based her suggestions primarily on what she saw or on what she heard, F1 answered that it was likely a combination of both, but she indicated that she seems to notice tension more in how the performers look than in how they sound. G1 answered that she believed she got more information from listening to the performance.

G2 and Undergraduate Participant Results

The second graduate participant's (G2) and undergraduates' (U1 and U2) gaze behavior varied more than did F1's and G1's gaze behavior across music and nonmusic video clips (Table 3.4). At times, G2's fixation data were like that of F1 and G1, but more often, G2's data were similar to the data of the undergraduate participants.

The fixation durations of G2, U1, and U2 were markedly different than those of F1 and G1. Unlike F1 and G1, the undergraduates' and G2's fixations were longest when watching the nonmusic clips rather than the flute clips. G2's and U2's fixations were shortest during flute clips, whereas U1's fixations were shortest during the clarinet and saxophone clips.

Table 3.4

G2, U1, and U2 Mean Fixation Data for Video Viewings: Duration Means, Rate, Mean Number of Targets Fixated, Mean Duration of First Fixation, Number of Target Changes in First Ten Seconds

Video Clip	**Participant**	**Mean Duration (ms)**	**# of Target Changes in First 10 s**	**Fixations per second (fps)**	**Number of Targets Fixated**	**Duration of First Fixation (ms)**	**Location of First Fixation**
Juggling	G2	814.29	8	0.70	5	866.67	Face
	U1	900.00	12	0.57	4	1266.67	Face
	U2	1015.69	6	0.57	5	566.67	Face
Ballet	G2	437.37	17	1.18	6	600.00	Face
	U1	350.00	20	1.07	4	633.33	Face
	U2	701.52	15	0.79	5	200.00	Tutu
Baseball	G2	422.22	16	1.30	11	466.67	Left Elbow
	U1	349.55	23	1.23	8	233.33	Face
	U2	633.33	11	0.90	11	700.00	Face
Clarinet 1	G2	638.67	16	1.32	10	300.00	Embouchure
	U1	408.57	14	1.84	9	200.00	Embouchure
	U2	670.83	16	1.26	9	1100.00	Embouchure
Clarinet 2	G2	465.48	19	1.47	10	433.33	Embouchure
	U1	551.39	17	1.26	10	266.67	Eyes
	U2	1018.75	13	0.84	7	1000.00	Embouchure
Sax 1	G2	466.67	18	1.53	10	600.00	Embouchure
	U1	481.33	10	1.47	8	700.00	Eyes
	U2	701.67	15	1.18	8	466.67	Embouchure
Sax 2	G2	545.45	18	1.16	7	300.00	Chest
	U1	415.38	13	1.37	7	766.67	Eyes
	U2	734.25	14	1.16	9	666.67	Embouchure
Flute 1	G2	419.54	13	1.00	8	200.00	Embouchure
	U1	416.67	19	1.58	9	267.67	Eyes
	U2	564.29	13	1.47	13	900.00	Embouchure
Flute 2	G2	447.44	16	1.44	11	300.00	RH, First Finger
	U1	462.67	20	1.39	7	233.33	Eyes
	U2	659.09	17	1.22	9	666.67	Flute Body
Flute 1 2nd View	G2	579.17	9	0.84	3	966.67	Embouchure
	U1	398.81	15	1.47	11	233.33	RH, First Finger
	U2	856.14	8	1.00	8	433.33	Right Palm
Flute 2 2nd View	G2	531.94	9	1.33	8	566.67	Embouchure
	U1	603.33	17	1.11	8	233.33	LH, Middle Finger
	U2	742.86	14	1.17	8	466.67	RH, Thumb

(continued)

Table 3.4 *G2, U1, and U2 Mean Fixation Data for Video Viewings* (continued)

Overall	G2	524.39	14.30	1.21	8.09	509.09
	U1	485.25	16.40	1.31	7.73	457.67
	U2	754.40	12.90	1.05	8.36	651.52
Nonmusic Clips	G2	557.96	13.00	1.06	7.33	644.45
	U1	533.18	18.30	0.96	5.33	711.11
	U2	783.51	10.70	0.75	7.00	488.89
Cl/Sax Clips	G2	529.07	17.80	1.37	9.25	408.33
	U1	464.17	13.50	1.49	8.50	483.34
	U2	781.38	14.50	1.11	8.25	808.34
Flute Clips	G2	494.52	11.80	1.15	7.50	508.34
	U1	470.27	17.80	1.39	8.75	241.92
	U2	705.60	13.00	1.22	9.50	616.67

Though their fixation durations were dissimilar from those of F1 and G1, G2's and the undergraduate participants' targets of fixation were more consistent with those of F1 and G1. Like F1 and G1, the three other participants fixated the fewest number of targets when watching the nonmusic clips. In this measure of overall targets fixated, G2 was more similar to F1 and G1 than to the undergraduates. G2 fixated the fewest targets during the nonmusic videos and the most targets during the clarinet and saxophone videos. G2 also switched targets the fewest times during the first 10 seconds of the flute videos (as did F1 and G1).

The undergraduates were similar to each other in this measure, but unalike from the more experienced participants. The undergraduates fixated the most targets overall when watching the flute videos, and switched the target of their fixations more frequently than did the artist-teacher and graduate participants during the first 10 seconds of the flute videos. F1 switched targets approximately 6 times during the first 10 seconds of the flute video clips. G1 and G2 switched targets fixation targets approximately 8 and 12 times, respectively, and the two undergraduate participants switched targets approximately 13 and 18 times in the first 10 seconds of the videos.

Both F1's and G1's longest initial fixations were when watching the flute videos and shortest when watching the nonmusic videos, and 14 of their initial 16 fixations were on the performers' embouchures. G2's initial fixations in the six music videos lasted between 200-966 ms, and her initial fixations of the flute players were shorter than were those of F1 and G1. G2's initial fixations in four of the six video clips of woodwind performers centered on the performers' embouchures; she first fixated the chest of the performer in the second saxophone video and the first finger of the performers' right hand in the second flute video. When watching the three video clips of nonmusic performers, her initial fixation was on the face of the juggler and ballet dancer, and on the left elbow of the baseball player. The initial fixations lasted between 466-866 ms.

Both undergraduates' initial fixations were shorter than were the artist-teacher and both graduate participants', in some cases only an eighth the duration of the artist-teacher's initial fixations. When U1 watched the video clips of woodwind performers, five her eight initial fixations were on the eyes of the performers, though during the first clarinet clip, U1's first fixation was on the performer's embouchure. During the second viewing of both flute clips, U1's first fixations were on the fingers of the performer. When U2 watched the video clips of woodwind performers, five of her eight initial fixations were on the embouchure of the performer, but the three other initial fixations were on the right hand of the performer or on the instrument. U1's initial fixations in the nonmusic clips were always on the face of the performer, and the initial fixations lasted between 233-1267 ms. U2 initially fixated the face of the juggler and the batter, and the tutu of the ballet dancer. Her initial fixations were between 200-700 ms.

Like F1 and G1, G2 and the undergraduate participants spent the greatest percentage of fixation time on the embouchures of the flute players (Flute 1 Clip: 50%; Flute 2 Clip: 30%; Flute 1 Clip 2nd Viewing: 69%; Flute 2 Clip 2nd Viewing: 49%). G2 and U2 also spent the greatest percentage of fixation time on the clarinet and saxophone players' embouchures as well. U1's gaze behavior during the clarinet and saxophone videos was dissimilar in that she spent the greatest percentage of fixation time on areas other than the embouchure (forehead, first finger of the right hand, and eyes) in three of the four clarinet and saxophone videos. During the nonmusic videos, G2's greatest percentage of fixation time was on the face of the performers (like F1 and G1), but U1 and U2 spent the greatest percentage of fixation time on the chest of the juggler, and U2 fixated the knees of the baseball player for the greatest percentage of fixation time.

As stated earlier, after viewing all nine video clips once, participants watched the two flute clips again and gave suggestions for improving the students' performances in each. After viewing each clip for the second time, G2 observed that the aperture of the performer in the first video seemed "tight" and suggested that he "open his mouth a little more." She also noted that his posture "could be improved" and indicated that she would like an opportunity to check the angle of his flute from a perspective other than what could be seen in the video. After re-watching the second flute video, G2 noted that the performer's flute was "not at a 90-degree angle with his face," so either he would need to tilt his head or the flute [to the left or right]. She noted that this performer's embouchure was also “tight,” and suggested that he also “open his mouth more.” She also mentioned that the performer’s posture and hand position “could be improved.” When asked if she noticed anything else about the performance, G2 answered that she thought he “looked angry as he played.”

Many of U1’s suggestions for the flute players were different from G2’s suggestions. After viewing the first flute clip for a second time, U1 noted that the performer’s aperture was “too big” and that he “should make it smaller.” She mentioned that she could not tell whether the performer was articulating and that he should “make that clearer to the listener.” She also stated that he should “round his fingers more.” U1 also noticed that the performer seemed “very relaxed and had his shoulders down.” She suggested that he lower the head joint on his face a little bit and have a “fuller bottom lip.” After re-watching the second video, U1 suggested that the performer “remain still as he starts notes because his embouchure sometimes moved.” She also suggested that he curve his fingers. U1 also noted that the performer “did not move his embouchure or air toward the end of the clip.”

U2’s suggestions were different from those of U1, but she gave one of the same suggestions as G2. After re-watching the first flute clip, U2 suggested that the performer’s right arm may have been back too far, which may have contributed to a “stuffy sound.” She also mentioned that the performer’s right-hand thumb was too far forward and that his fingers were “too close together.” She suggested that the performer adjust his embouchure to “focus the air.” Like G2 mentioned, U2 suggested that the performer in the second clip change the angle of his flute to be more in line with his aperture. She also suggested that he “focus his air” and play to one side of his aperture given that he had a tear-drop lip shape.

During the post-eye-tracking interview, G2 answered that when watching a new student perform for the first time, she typically pays attention to embouchure the most, including the flute placement on the face and the size of the aperture related to how the performer is shaping the air. G2 said she also typically looks at the hands and body position, because posture and setup are important aspects of producing sound on the flute. When asked whether she based her suggestions primarily on what she saw or what she heard, she answered that she considered what she saw and what she heard, but her comments about the students’ posture and flute angles were based on what she saw.

During the post-eye-tracking interviews, both undergraduate participants said that they prioritize the appearance of the embouchure, the sound of the tone, and the setup of the instrument on the face. U1 said that she first listens to the sound, which then may direct her to look at the embouchure and other aspects of physical position. U2 reported that she looks first at the embouchure then the setup. Then she listens for a fuzzy or stuffy tone. Both undergraduates seemed to think that their priorities would change when working with students of different ages and experience levels. U1 and U2 mentioned that if they were watching a more experienced performer, they would both listen for tone and then look to see how the performer was achieving that tone. Both participants mentioned that more experienced performers’ embouchures and setups were already established. U1 believed that her suggestions for both performers were primarily based on what she heard. U1 believed that the visual aspects of the first flute performer contributed to her suggestions because she saw an issue with the position of the flute. U1 believed that the sound primarily contributed to her suggestions for the performer in the second flute video. When asked whether she based her suggestions primarily on what she saw or on what she heard, U2 answered that she believed she got more information from listening to the performance.

DISCUSSION

We examined the eye movements of flute players of different experience levels (i.e., faculty, graduate, and undergraduate) as they watched videos of individuals performing on woodwind instruments and performing other skills (i.e., juggling, baseball, and ballet). The gaze behavior of the participants did not always align with their level of experience and confirmed previous research that experience does not necessarily generate expertise (Ericsson, 2008; Ericsson et al., 1993; Feigenbaum & Simon, 1984; Richman et al., 1995). The artist-teacher's gaze behavior (i.e., her scan paths during the video clips and her fixation data) consistently demonstrated her thought process and priorities when watching a new student perform – she looked at the most informative targets on the performer and fixated these targets longer than did other participants. One graduate participant's (G1) gaze behavior was much like that of the artist-teacher's, and the second graduate (G2) and both undergraduate participants' gaze behavior differed from one another. Frequently, G2's gaze behavior was more similar to the undergraduates' gaze behavior than to F1 and G1, and the two undergraduate participants' gaze behavior was often unalike. Though G1's gaze behavior appeared similar to that of F1's in many respects, it is clear that F1's overall gaze behavior, especially when watching videos within her area of expertise, was fundamentally different than that of the other participants.

It has been shown in a variety of domains that experts tend to focus on the most informative aspects of a scene more so than do novices (e.g., Bilalić et al., 2010; Gobet & Simon, 2006; Kundel et al., 2007; Waters & Underwood, 1998). F1's first fixations all landed on the embouchures of the music performers and on the faces of the nonmusic performers. Her immediate focus on the music performers' embouchures and her fixation time spent on that target indicate her priority when assessing an unfamiliar performer. Her gaze reflects her conception that the embouchure will provide the most information about the performers' capabilities. These data are consistent with other research that demonstrates experts' ability to quickly attend to the most important aspects of a scene (e.g., Ballard et al., 1992, Ballard et al., 1995; Land & Hayhoe, 2001; Pelz & Canosa, 2001; Taya et al., 2013). Twelve of the graduate participants' first 16 fixations during the music videos were on the embouchure of the music performers and five of six initial fixations during the nonmusic videos were on the faces of the nonmusic performers. Only 6 of the undergraduate participants' first 16 fixations were on the embouchures of the music performers. These data suggest that the more-experienced graduate students had learned to focus on embouchures as primary determinants of sound production, whereas the undergraduates' fixations did not reflect the same priority.

Not only were the locations of F1's and G1's first fixations informative, the duration of the fixations on those locations also provided time for the expert participant to gain information. The mean duration of F1's initial fixations on the flute players was longer than any other participant's mean initial fixation durations. Though G1's fixations were longer than G2 and the undergraduates, the mean durations of her initial fixations when viewing the flute clips were not as long as were the artist-teacher's. The undergraduates' and G2's initial fixations during the flute videos were much shorter than were the artist-teacher's and G1's initial fixations, sometimes almost an eighth the duration of F1's fixations. F1's and G1's longer fixation durations during the flute videos and their initial fixations of the flute performers' embouchures may indicate their capacity to gain more information from sustained focus on dynamic elements of a visual stimulus; they fixated the embouchures longer because, for them, there was "more to see" in the dynamics of the embouchure over time.

The number of times the participants switched the target of their fixation in the first 10 seconds of each video clip also indicates differences in their thinking and allocation of attention. The artist-teacher and both graduate participants fixated the most important aspect of the performer (i.e., the embouchure) quickly without looking at other targets first, whereas the undergraduate participants looked at several different targets during the beginning of each video. F1 and G1 typically remained on their initial target, whereas G2 switched to other targets. The undergraduates often fixated other elements before the embouchure and then continued to switch among other targets. The undergraduates appeared to scan the scene before fixating the embouchure. The combination of overall fixation durations, initial fixation durations, and the number of target switches indicates the experts' thought process of looking for the most informative element of the performer and continuing to observe the subtle changes that may take place in the embouchure over time. The undergraduates did not demonstrate the same process.

Our task was designed to include videos of content that was in the participants' area of expertise (flute), closely related to their area of expertise (other woodwinds), and content in which the participants had had little past experience (juggling, baseball, and ballet). The artist-teacher's and G1's mean fixation durations were longest when they watched the flute videos and were shortest when they watched the nonmusic performers. This finding is consistent with expertise literature, which suggests that experts typically fixate longer than do novices when both are viewing the same scene (Gegenfurtner et al., 2011; Gilman & Underwood, 2003; Marcum & Duke, 2017; Savelsbergh et al., 2002; Savelsbergh et al., 2005). The fixation durations of G2 and the undergraduate participants were longest when watching the nonmusic performances. G2's and U2's fixations were actually shortest when watching the flute clips, whereas U1's fixations were shortest during the clarinet and saxophone clips. Despite these participants' experience playing and teaching flute, their fixation durations indicated different patterns of perception than did F1 and G1, whose gaze behavior seemed driven by clear goals and well-established instructional priorities.

Fixation duration, both overall mean durations and initial fixation durations, was one of the measures that clearly defined participants in terms of expertise. F1 and G1's fixations were notably longer than were the other participants'. Some literature suggests that because of experts' experiences and background knowledge stored in memory, experts are able to absorb more information from a *short* fixation than are novices (Drai-Zerbib & Baccino, 2014; Kasarskis et al., 2001; Truitt et al., 1997; Waters et al., 1997). Eye movements, however, are heavily influenced by the task instructions and the nature of the stimulus. Studies that indicate shorter expert fixations often involve tasks in which participants must find a target item in a static scene (e.g., differences in two musical passages, lesion on a chest x-ray) (Drai-Zerbib & Baccino, 2014; Kasarskis et al., 2001; Truitt et al., 1997; Waters et al., 1997). These tasks do not include any incentive for longer fixations – the task is to find a target quickly.

Other research results suggest that experts fixate *longer* than do novices during tasks in which it is advantageous to acquire information from evolving dynamic scenes before making a decision (Savelsbergh et al., 2002; Savelsbergh et al., 2005; Gilman & Underwood, 2003; Marcum & Duke, 2017). Expert soccer goalies, for example, fixate longer on their opponents than do novices during penalty kicks before making a decision about which direction they need to move to block the shot (e.g., Savelsbergh et al., 2002; Savelsbergh et al., 2005). The expert goalies absorb as much information about the opponent's intentions before moving to block the kick, increasing their chances of success.

The longer fixation durations of F1 and G1 and the nature of the task are consistent with the results of the latter studies. Watching individuals engaged in skilled performance and formulating suggestions for improved performance elicited longer fixation, affording viewers more information that a quick fixation may provide. F1 and

G1 may have been noticing small changes in the mouth and embouchure as the performer played.

There was a wealth of information to be gained by studying the embouchure over time that could not be acquired from a quick glance; for experts, there is simply more to see in a functioning embouchure than may be perceived by less expert observers. There are many facets of a correct embouchure, including lip fullness, engagement of the corners of the lips, amount of lip covering the tone hole (flute) or around the mouthpiece (clarinet and saxophone), aperture size, and the orientation of the instrument to the embouchure and aperture. It would seem quite difficult to evaluate all of these dimensions, and how they may change as the player produces tones, with only brief fixations. An expert flute teacher, even when watching other instrumentalists play, may check all of these aspects to ensure that the performer’s embouchure is operating correctly before attending to other aspects of the performance.

F1’s and G1’s first fixation durations were the longest when they watched the flute performers, which, again, is consistent with expertise research. In addition, the majority of their fixation time was spent looking at the face and embouchure, and they changed their fixation targets much less frequently than did the other participants (Figure 3.2, yellow lines). Marcum and Duke (2017) also found that expert string teachers fixated fewer targets than did less-experienced teachers while watching students perform. The location and duration of the F1’s and G1’s fixations may be indicative of clear and precise goals associated with flute playing; they did not fixate areas irrelevant to the task.

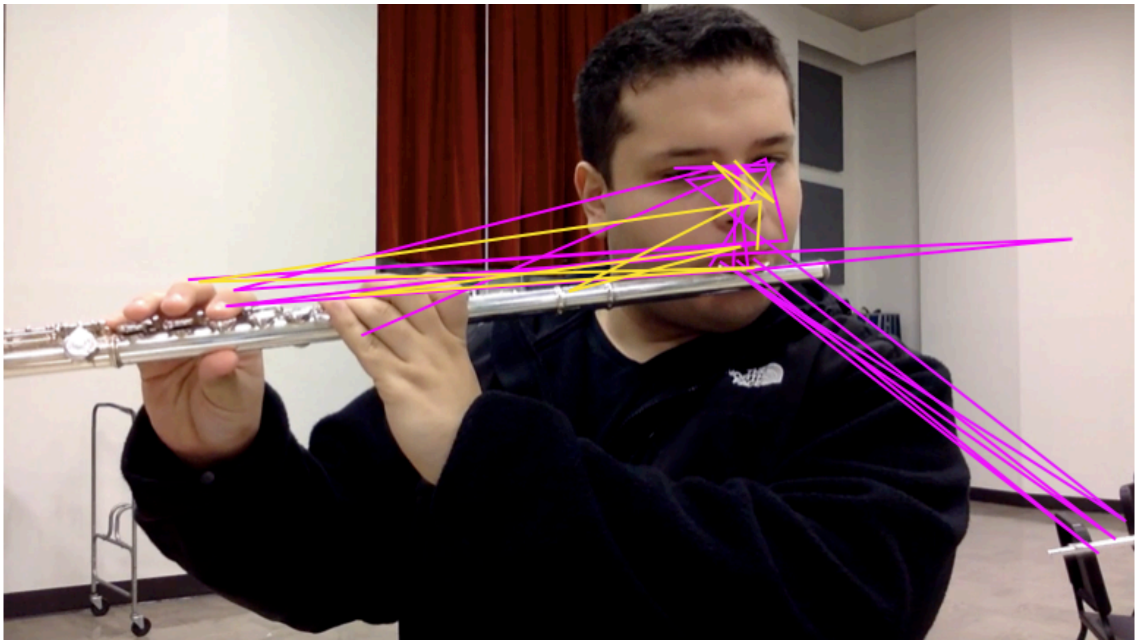


Figure 3.2: Participant (F1 and U1) scan paths during the Flute 2 video clip. F1's path is shown in yellow, and U1's scan path is shown in purple.

Though the undergraduate participants did not exhibit long fixation durations similar to those of F1 and G1, the undergraduates did spend the greatest proportion of their viewing time fixating the embouchures of the music performers and the faces of the nonmusic performers. However, U1 and U2 switched the target of their fixations more frequently during the first 10 seconds of the video clips than did the faculty and graduate participants. Interestingly, many of the targets fixated by the undergraduate participants were the same targets fixated by the faculty member, but these less-experienced participants fixated other locations as well, including areas away from the performer entirely (e.g., a chair in the room or the wall) (Figure 3.2, purple lines). These participants seemed aware of the informative targets on the instrumentalists, but they did not persist in fixating those targets, which may be a reflection of their inability to gain as much information from a given fixation as might be gained by an expert.

We had expected that the five participants' gaze behavior would look more alike during the nonmusic videos than during the flute videos. All participants' gaze behavior was consistent with the findings of research showing that viewers typically fixate the face of a person in a scene if there are no other behavioral goals for visual search (Bindemann et al., 2005; Birmingham et al., 2008; Birmingham et al., 2009; Fletcher-Watson et al., 2008; Freeth et al., 2010; Ro et al., 2001; Rösler et al., 2017; Smith & Mital, 2013; Suda & Kitazawa, 2015; Theeuwes & Stigchel, 2006; & Vuilleumier, 2000). Although participants were instructed to think of three suggestions to improve all of the performances (music and nonmusic) as they watched each video clip, participants' lack of experience or expertise led to their looking at the faces of the nonmusic performers.

The results of this study provide a demonstration of the some of the distinctive features of gaze behavior by experts in music and demonstrate that experience alone does not necessarily lead to expertise. Much of the results reported here are consistent with the results of earlier investigations in other domains and with other types of tasks. The fixation durations, frequencies, numbers of target changes, and fixation locations of the artist-teacher and one of the graduate participants in this investigation reflect a hierarchical attention to the physical elements that contribute to excellent instrument playing. G2 also prioritized the performers' embouchures, though her fixations were shorter than were F1's and G1's, and she fixated more locations of the performer than did F1 and G1. The undergraduates fixated more targets than did the more experienced participants, and did not fixate the most informative targets for as long as the faculty and graduates did.

These results again demonstrate the difference between the expert participants *looking for* specific targets and the non-expert participants *looking at* the performer. Some research suggests that experts watching a dynamic scene (i.e., video or live environment) tend to fixate longer than do novices, seemingly to glean as much information from the scene as possible before making a decision (Savelsbergh et al., 2002; Savelsbergh et al., 2005; Gilman & Underwood, 2003; Marcum & Duke, 2017). Given the artist-teacher's and G1's experience playing and teaching flute, they have likely learned the types and extent of information to be gained by fixating critical locations on the face and body and have been rewarded by obtaining insights that they can employ to improve their students' performances. Perhaps surprisingly, though G2 years of performance and teaching experience were similar to those of G1, her gaze behavior when watching flute students perform did not reflect the same priorities. The undergraduates most certainly understood that the embouchure is an important part of flute playing, but they may have noticed less of what was taking place in a functioning embouchure and thus, their fixations were reflective of how much (or how little) they gained from looking.

The design of this investigation included important limitations that should be carefully considered when interpreting the results. Participants observed video recordings rather than live performances, and the performances were brief and afforded observers only one visual perspective. The sample of participants included only five female flautists, focusing on one music performance medium in an effort to compare gaze behavior in circumstances that were similar and dissimilar to participants' typical professional and personal experiences.

All participants stated in their post-eye-tracking interviews that their assessments of the performers were informed by a combination of what they saw and what they heard, but we cannot determine specifically how each facet of the video affected participants' allocations of attention. The present study provides new information about music teachers' attention allocation and offers new insights into differences in thinking and perception between experts and nonexperts in music.

Chapter IV: Discussion

The nature of expertise in teaching and in other domains for decades has been a topic of systematic inquiry (e.g., Berliner, 1986, 1988, 2001, 2004; Bereiter & Scardamalia, 1993; Bilalić, 2018; Carter et al., 1988; Chi, 2006; Duke & Simmons, 2006; Ericsson, 2008; Ericsson et al., 1993; Gobet, 2016; Madsen et al., 1992). Systematic observation, structured interviews, and think-aloud protocols all have been deployed in efforts to better understand how and why experts think and behave as they do (e.g., Ericsson & Simon, 1998; Ericsson & Simon, 1984; Jääskeläinen, 2010; Fonteyn et al., 1993). Although a wealth of literature has revealed a great deal about the processes involved in teacher thinking and decision making, teachers' allocation of attention and perception have received much less attention (e.g., Bargh & Morsella, 2008; Damasio, Everitt, Bishop, Roberts, Robbins, & Weiskrantz, 1996; Fonteyn et al., 1993; Nisbett & Wilson, 1977; Wilson & Brekke, 1994). Eye-tracking technology has shown great promise in revealing heretofore unknown aspects of expert thinking.

Though eye-tracking has been used in the study of expertise in other domains, it is relatively new in music-teaching research. Marcum and Duke (2017) pioneered this technology in studying music-teacher gaze behavior and cognition, obtaining promising results. Marcum and Duke discovered that expert string teachers, like experts in other fields, fixate targets in their visual field that are most useful in accomplishing proximal performance goals, and their gaze lingers on these locations, exploiting the available information that persistent fixations of dynamic motor behavior provide. This expert-teacher gaze behavior was apparent in lessons with familiar and unfamiliar students alike, and less-experienced string teachers exhibited different gaze behavior from that of the experts. The second study described in the preceding chapter extends this work by examining gaze behavior of wind instrumentalists viewing different types of activity within and outside their own areas of experience and expertise.

Reading full ensemble scores is a prominent feature in the work of instrumental music teachers and conductors, both during rehearsal planning and during active rehearsing, but music-reading studies to date have focused on reading more compressed forms of music notation, either single lines or piano scores (Arthur et al., 2016; Burman & Booth, 2009; Cara & Gomez, 2016; Drai-Zerbib & Baccino, 2014; Furneaux & Land, 1999; Gilman & Underwood, 2003; Goolsby 1989, 1994a, 1994b; Hoppe et al., 2014; Kinsler & Carpenter, 1995; Madell & Hééebert, 2008; Penttinen et al., 2013; Rayner & Pollatsek, 1997; Silva & Castro, 2018; Sloboda, 1974; Truitt et al., 1997; Waters & Underwood, 1998; Waters et al., 1997; Weaver 1943). No published research to date has studied the gaze behavior of ensemble conductors as they read music scores, and the first study in this dissertation was designed to fill this gap in the literature.

Gaze Behavior of Experts and Novices

It is well understood that gaze behavior is heavily dependent upon the nature of the task and behavioral goals associated with the task (Dorr et al., 2010; Hayhoe et al., 2003; Hayhoe & Ballard, 2005; Jarodzka et al., 2010; Kandil et al., 2009; Land, 2009; Land & Furneaux, 1997; Land & Hayhoe, 2001; Pelz & Canosa, 2001; Shinoda et al., 2001; Smith & Mital, 2013; Wang et al., 2012). Studies of expert behavior, including studies that seek to differentiate the gaze behaviors of experts and novices, have measured fixation timing, fixation frequency, fixation duration, fixation location, and saccade distance.

Participants who are asked to view a static image and locate a target or compare different static images (e.g., finding a mass on a chest x-ray or finding the difference between two fragments of written music) complete the assigned tasks as soon as the target is located. Experts typically outperform nonexperts in terms of time required, with fixation durations that tend to be shorter, given experts' background domain knowledge and pattern recognition capabilities (e.g., Donovan & Litchfield, 2013; Kasarskis et al., 2001; Truitt et al., 1997). Tasks that involve observations of dynamic scenes that change over time require longer fixation times as experts seek to determine how the scene is unfolding, noticing additional and smaller moment-to-moment changes than are typically perceived by novices (e.g., Gilman & Underwood, 2003; Marcum & Duke, 2017; Savelsbergh et al., 2002; Savelsbergh et al., 2005). Because experts notice more of the small differences that may take place moment-to-moment, they seem to recognize implicitly that there is *more to learn* from longer fixations. The gaze behavior of nonexperts, in contrast, suggests that after short fixations, nonexperts have "seen enough," as they are unable to discriminate the small changes that may be unfolding before their eyes (but below their thresholds of discrimination) and fail to recognize how these changes may contribute to deeper understanding and improved decision making. These findings illustrate how fixation durations vary as a function of task goals and participant expertise.

Results from the two studies presented above are consistent with previous research that suggests gaze behavior is tightly linked to task goals. In the score-reading study, experts fixated for shorter durations than did novices, but novices fixated for shorter durations than did graduate-level participants. The experts' shorter fixations are in keeping with previous research showing that experts locate visual targets quickly, and the score-reading experts' short fixations likely reflect their ability to process musical notation quickly. It was surprising to find that the undergraduate conductors' fixations, though longer than the experts', were shorter than the graduates'. One explanation for this difference may be that the undergraduate participants prioritized keeping pace with the ongoing music or metronome and were not attempting to imagine all of the voices of the music's texture as they followed along in the score. The graduate conductors, whose fixations tended to be longer than the faculty conductors', may in fact have been imagining the music as they read the score, and in doing so, these participants required longer fixations than were required for the faculty. All participants' fixation frequencies were similar across all score readings, as were saccade distances, but the experts switched the target of their gaze more frequently than did graduate and undergraduate participants.

In the performance-observation study, the artist-teacher tended to fixate a given target longer than did the other participants, especially in the flute performances. The artist-teacher also switched the target of her fixations less frequently than did the graduate and undergraduate participants. These longer fixations by the artist-teacher (as well as one of the graduate student participants) are in keeping with the notion that experts' superior discrimination ability results in accessing more available information at a given fixation location. Experts fixate longer because, for them, there is simply more to learn from observing the dynamics of ongoing behavior.

The data from these two studies are illustrative of the differences in looking time that vary with the expertise of the observer as well as the nature of the task at hand and its proximal goals. In the score reading task, shorter fixation durations and frequent shifts of fixation targets characterized the gaze behavior of the expert conductors. In an observation task with pedagogical goals, longer fixation durations and fewer target switches were associated with the behavior of the most skillful participants. In the score reading task, it was advantageous for the experts to fixate targets quickly so that they could keep pace with the ongoing music or metronome while at the same time perceiving and imagining the entirety of the ensemble texture. In the observation task, it was advantageous for the experts to persist longer on informative targets in order to gain as much information as possible as the dynamics of the scene progressed.

TARGETS OF EXPERT FIXATIONS

It has been demonstrated in a variety of contexts that experts tend to quickly fixate the most informative aspects of a given scene (e.g., Ballard et al., 1992; Ballard et al., 1995; Land & Hayhoe, 2001; Marcum & Duke, 2017; Pelz & Canosa, 2001; Taya et al., 2013). The results of the studies reported in this dissertation are consistent with those findings. What most clearly differentiated the gaze behavior of experts from that of nonexperts was the combination of the targets and timing of expert fixations. In the score-reading study, the faculty participants, and often graduate participants, fixated informative elements of the score in anticipation of their occurrence in the ongoing music (heard or imagined). Experts tended to fixate entrances, phrase beginnings, texture changes, and releases of many different instrument lines before these events occurred in time. The undergraduate participants either fixated similar targets *after* they had passed, or they followed a single line of music, seldom fixating different instrument parts in the score. The gaze behavior of experts may reflect the effects of decades of experience in which their understanding, planning, and actions have been advantaged by their gaze patterns in reading full scores, patterns that have been reinforced over time. Being able to consider fully a multi-voice texture and to anticipate important elements of the music are requisite components of conductors' skills. The gaze behavior of the undergraduates, who had little experience working with full ensembles, reflected a more reactive mode of reading and thinking about the music with which they were presented, and suggested that they had limited capacity to consider multiple instrument lines simultaneously as the music progressed.

Participants' gaze behavior during score reading may also reveal important differences in musicians' conceptions of the music they engage with. Note that the more expert conductors kept pace with the ongoing music, real or imagined, but they continued to shift their gaze to multiple elements of the music texture, something that the novices did much less frequently. This may reflect how these participants actually *perceive* music with complex, multi-voice textures. The fact that the least experienced participants tended to fixate the principal lines may be an indication of their auditory processing of the music as well. It may be that the principal lines (often melodies) are more prominently in the foreground of less experienced musicians' conceptions of music than they are in the conceptions of experts. Just as text readers capture words and short phrases in single fixations, and just as readers of single line music notation capture note groupings in single fixations, skillful conductors (who are presumably more advanced musicians in most respects than are the undergraduate participants) may in fact process multi-voice music not as a collection of separate lines of activity, but as a cohesive amalgam of sounds that blend together as a unified whole. The fact that experts' gaze behavior evinced frequent fixations on diverse elements of the music texture that were notated on different lines of the score seems entirely consistent with this hypothesis.

Similarly, in the performance-observation study, and especially in the instrumental music videos, the faculty participant fixated almost exclusively the most informative aspects of the performers' behavior, and her gaze remained on those targets longer than did other participants'. While watching all of the instrumental music videos, and especially the flute videos, the faculty participant immediately fixated the performers' embouchures, where her gaze remained for much of the clip. Nor did she switch the target of her fixations as frequently as did the other participants. The graduate and undergraduate participants not only fixated more varied targets than did the artist-teacher, but their fixations on the informative elements of the performer were much shorter than were the expert's.

The nonexpert flautists were certainly well aware of the centrality of embouchure formation and position in excellent flute playing, but they did not appear to recognize what may be gained by fixating targets long enough to observe changes that unfold over time. They may in some ways regard a short fixation on the embouchure as they would a static element whose small changes moment-to-moment do not contribute to a fuller understanding of skills and limitations of the musician being observed.

We expected participants' gaze behavior to be much more alike during the nonmusic videos than during the music videos, since all participants lacked expertise in juggling, baseball, and ballet. This prediction was confirmed, as the participants' overall fixation durations, initial fixation durations, and target switches were more similar during nonmusic clips than during the clips of instrumental musicians. Interestingly, the less-expert participants (G2, U1, and U2) displayed greater attentional focus (longer initial fixation durations, longer overall durations, fewest total targets fixated) during the nonmusic clips, their area of least expertise, than they had during the instrumental music clips. The fact that F1 and G1's longest fixations occurred while observing the instrumental music clips and the other three participants' longest fixations occurred while watching the nonmusic clips deserves further consideration.

Clearly, experts develop different ways of perceiving and thinking about the visual elements of their domains of expertise, and this is reflected in their gaze behavior. There are two aspects of the observations in the two studies that seem particularly important. The first is the extent to which gaze behavior in score reading may be indicative of how musicians are perceiving music as it unfolds over time. The fact that expert conductors' switch their gaze among important elements in the score that represent the multifarious elements of ensemble music may indeed be an indicator of the extent to which they are actively processing the multiple elements of the incoming auditory stream. This raises questions that are certainly worthy of further research. Does gaze behavior in fact reflect what listeners hear in complex music stimuli?

The second aspect concerns the perception and analysis of the dynamics of fine motor behavior. It seems that the longer fixation durations of the artist-teacher and one of the graduate students are reflective of both acquired visual discrimination capacity in the domain specialty (flute playing, in this case) and awareness of the changing nature of fine motor movements engaged during highly skilled behavior. These results are wholly consistent with those reported in Marcum's dissertation (2017).

APPLICATIONS IN MUSIC TEACHING AND LEARNING AND FUTURE RESEARCH

Eye-tracking research in music teaching and learning is still quite new, and there is much to learn from further research. It is unknown at present whether revealing the ways that experts attend to the stimuli in their environments, either by communicating the findings of studies like those reported here or by presenting videos of the tracks of expert gaze, would inform nonexperts in ways that would affect their subsequent behavior. Future research should pursue this line of inquiry. Since there have been such things as teachers and learners, efforts have been made to enhance or accelerate the acquisition of knowledge and skills in pedagogy and in other domains. Whether knowing more about how experts perceive the world and allocate attention may, in fact, affect the development of aspiring novices is an open question. This is not to suggest that deliberate practice is not a central element of skill learning, but knowing more about the covert behavior of practicing professionals as they perceive the world around them and formulate plans of action may indeed affect the learning experiences of novices, informing deliberate practice in ways that have yet to be clarified or exploited.

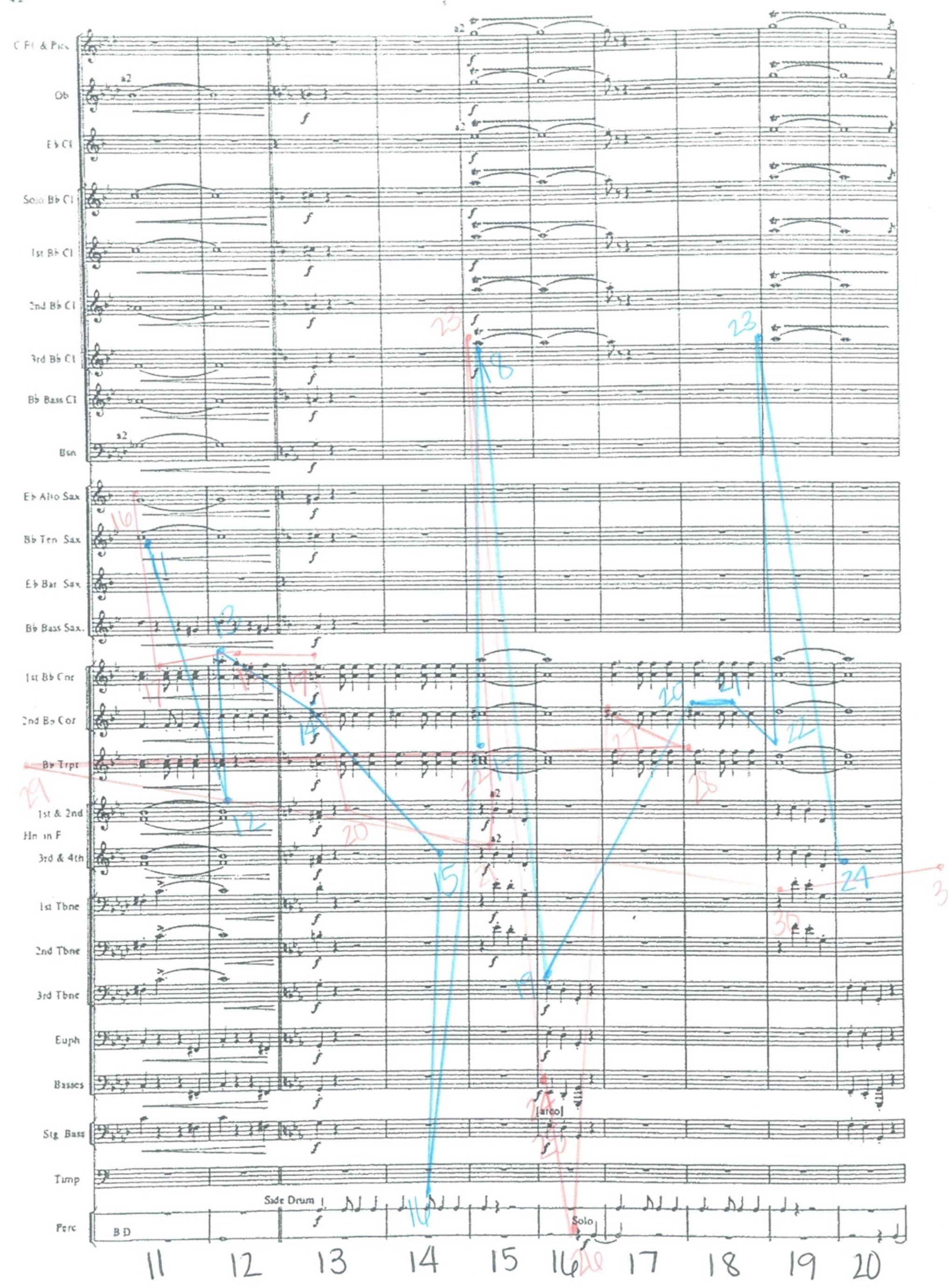
One of the most important limitations in both of the reported studies was the small number of participants. Eye-tracking technology provides new insights into perception and thought processes, but data collection and analysis are time-consuming. Yet, it seems important to observe the behavior of larger numbers of participants to assess the extent to which individuals vary in their approaches to complex tasks.

As our understanding of the relationships between gaze behavior and thinking in complex environments increases, the findings of gaze analyses may suggest new approaches to cultivating skills in learners. It appears that the kinds of information obtained in this dissertation, as well as the information provided by Marcum, may inform the development of more targeted approaches to acquiring and refining skills, not only in music teaching, but in other domains as well.

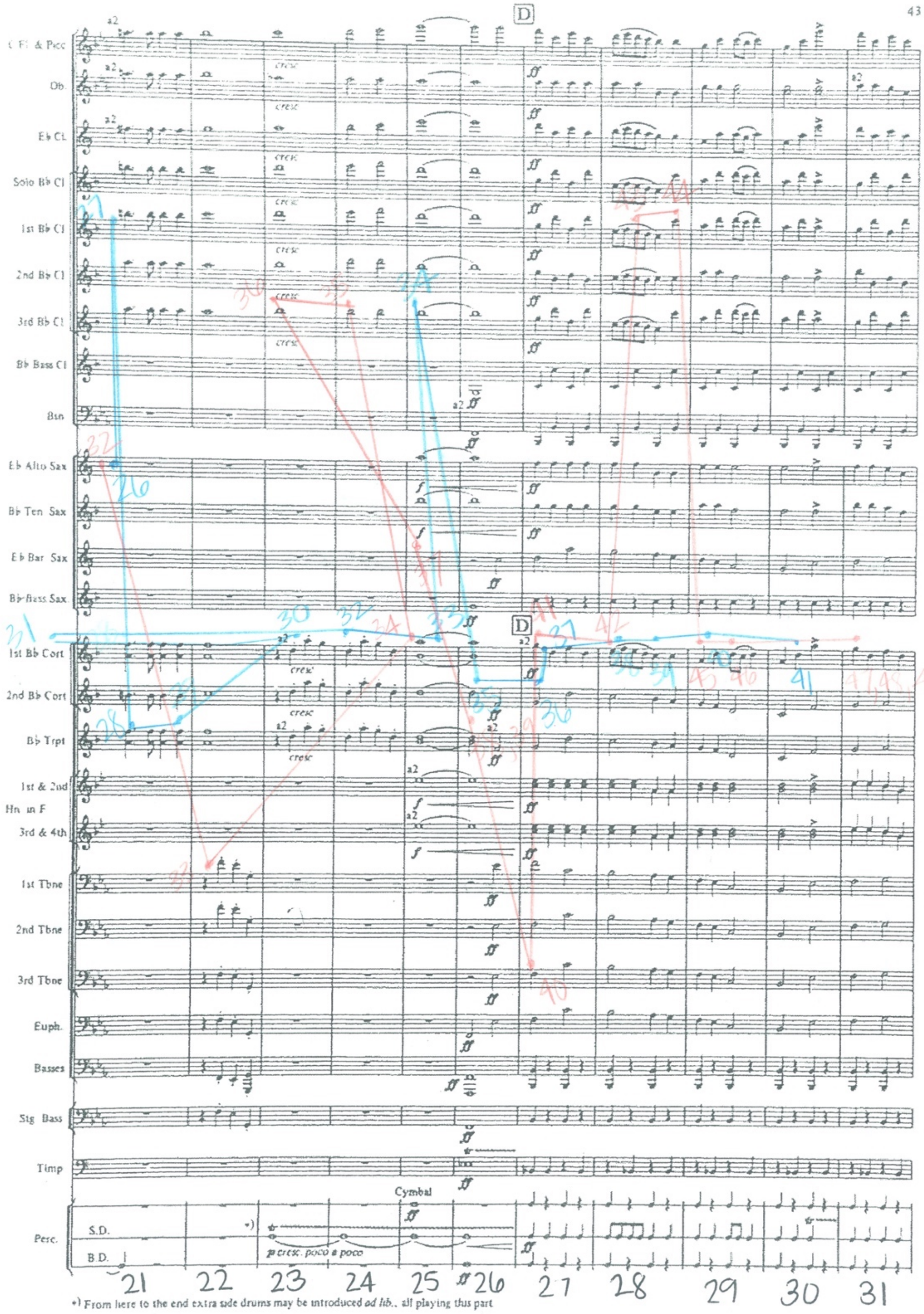
Appendices

APPENDIX A: EXPERIMENT 1 – SCORE COPIES AND PARTICIPANT SCAN PATHS

F1

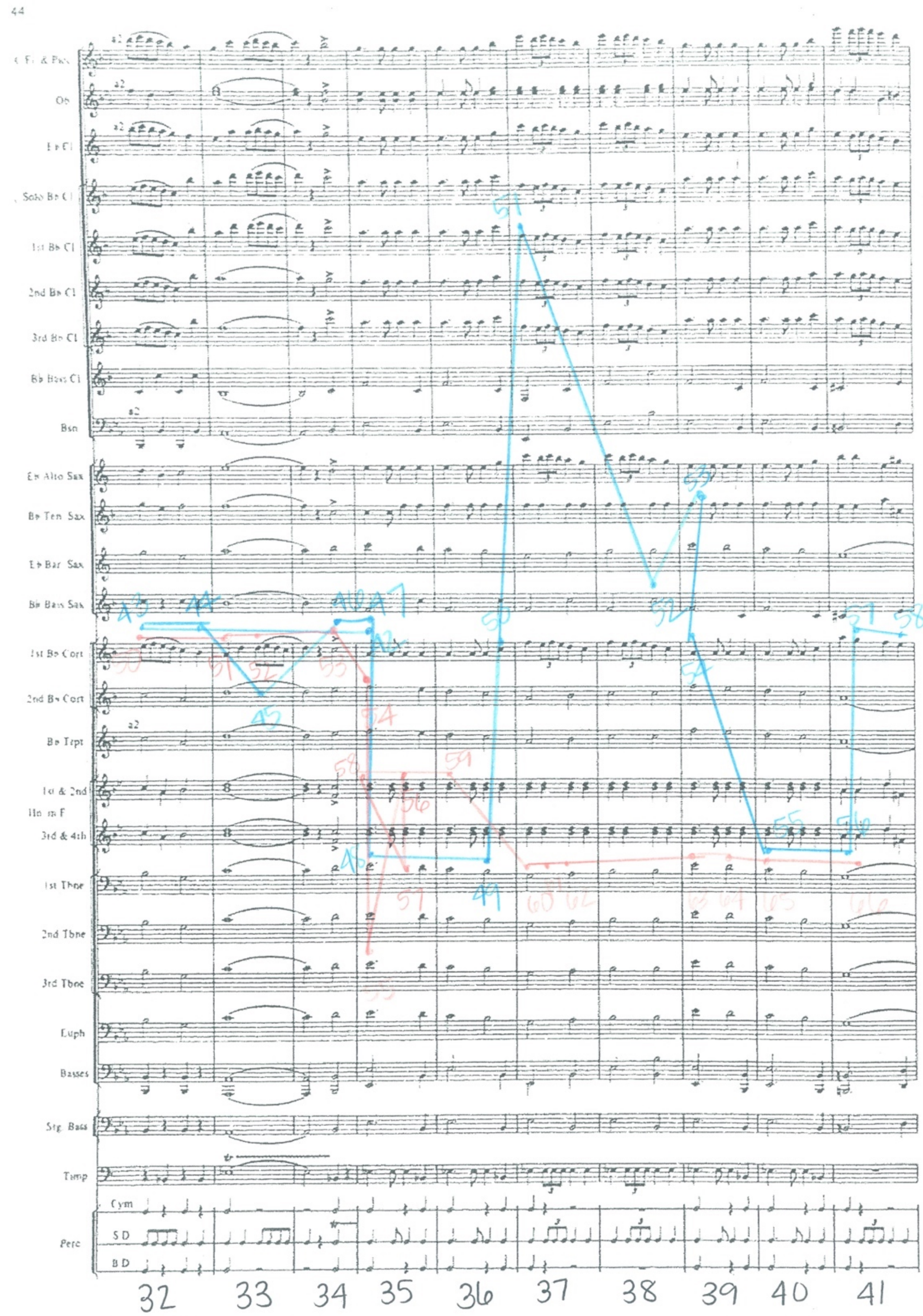

42
C Fl & Picc
Ob
E♭ Cl
Solo B♭ Cl
1st B♭ Cl
2nd B♭ Cl
3rd B♭ Cl
B♭ Bass Cl
Bsn
E♭ Alto Sax
B♭ Ten Sax
E♭ Bar Sax
B♭ Bass Sax.
1st B♭ Cor
2nd B♭ Cor
B♭ Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Perc
Side Drum
B D
Solo
arco
a2
11
12
13
14
15
16
17
18
19
20

F1

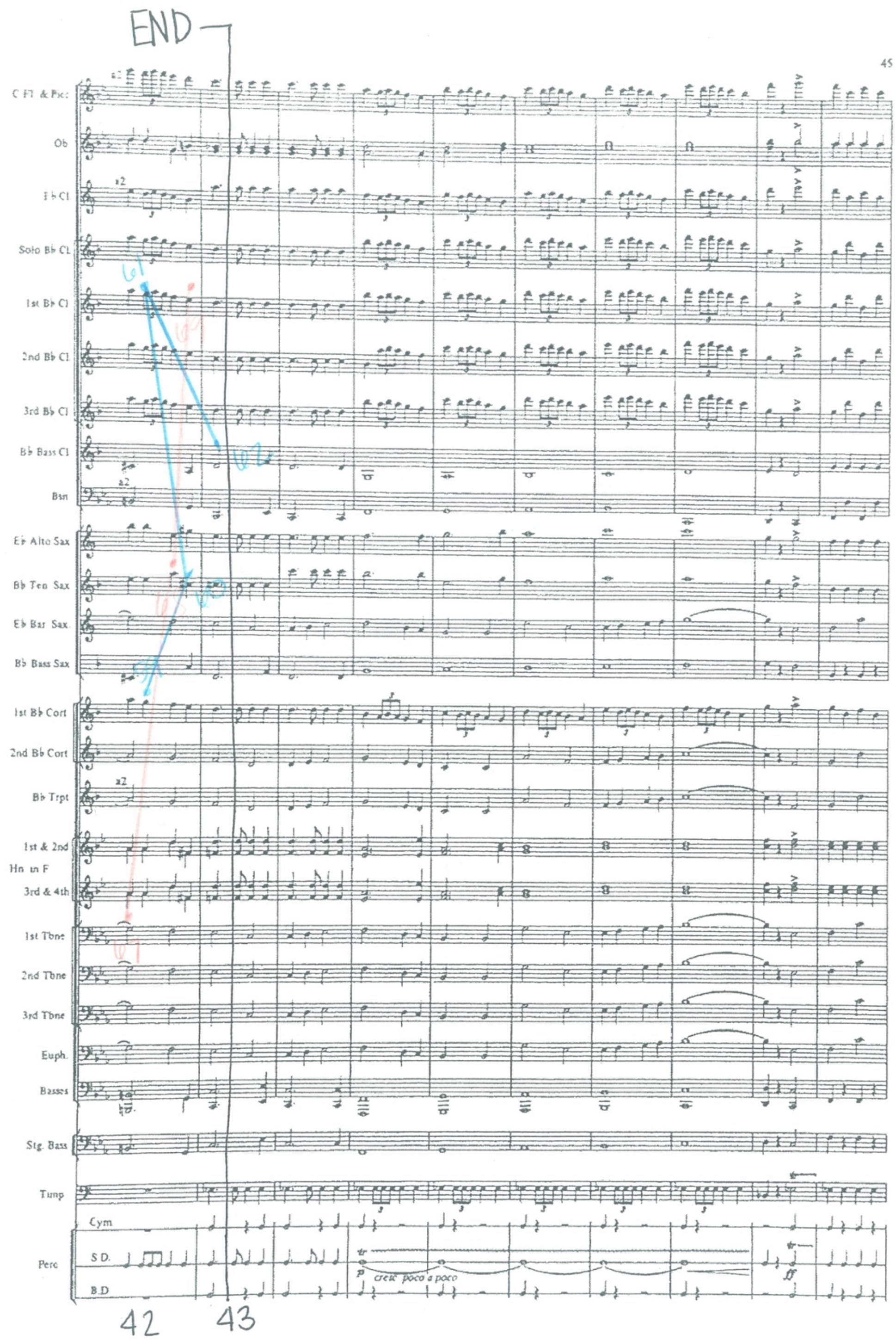


*) From here to the end extra side drums may be introduced *ad lib.*, all playing this part

F1


44
Fl & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cort
2nd Bb Cort
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Cym
SD
BD
Perc
32
33
34
35
36
37
38
39
40
41

F1

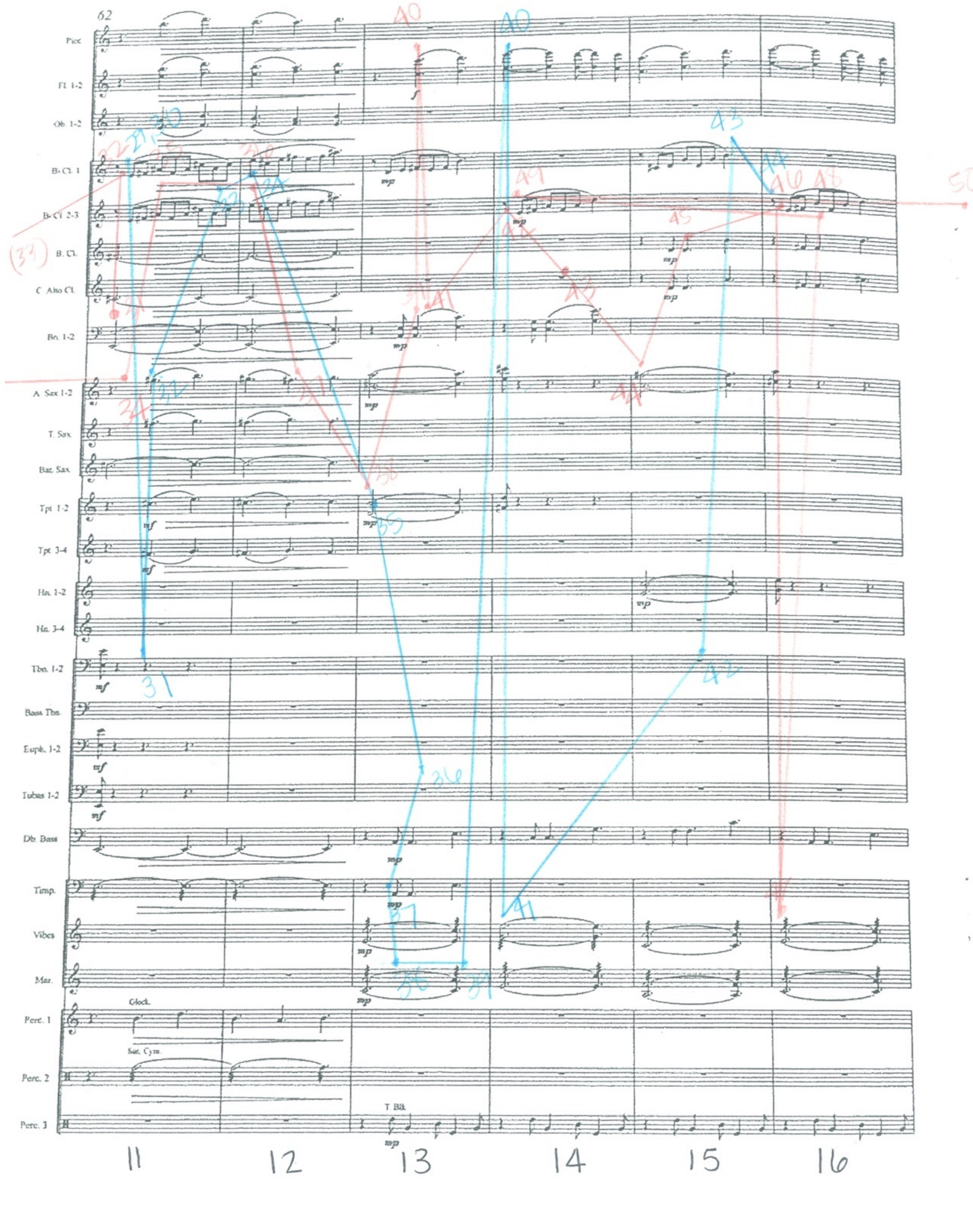

END
45
C Fl & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cort
2nd Bb Cort
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph.
Basses
Stg. Bass
Timp
Cym
Perc
S.D.
B.D.
cresc poco a poco
42
43


= metronome
= audio
10
EWAZEN
START
F1
48
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Toms
Glock.
Sus. Cym.
1
2

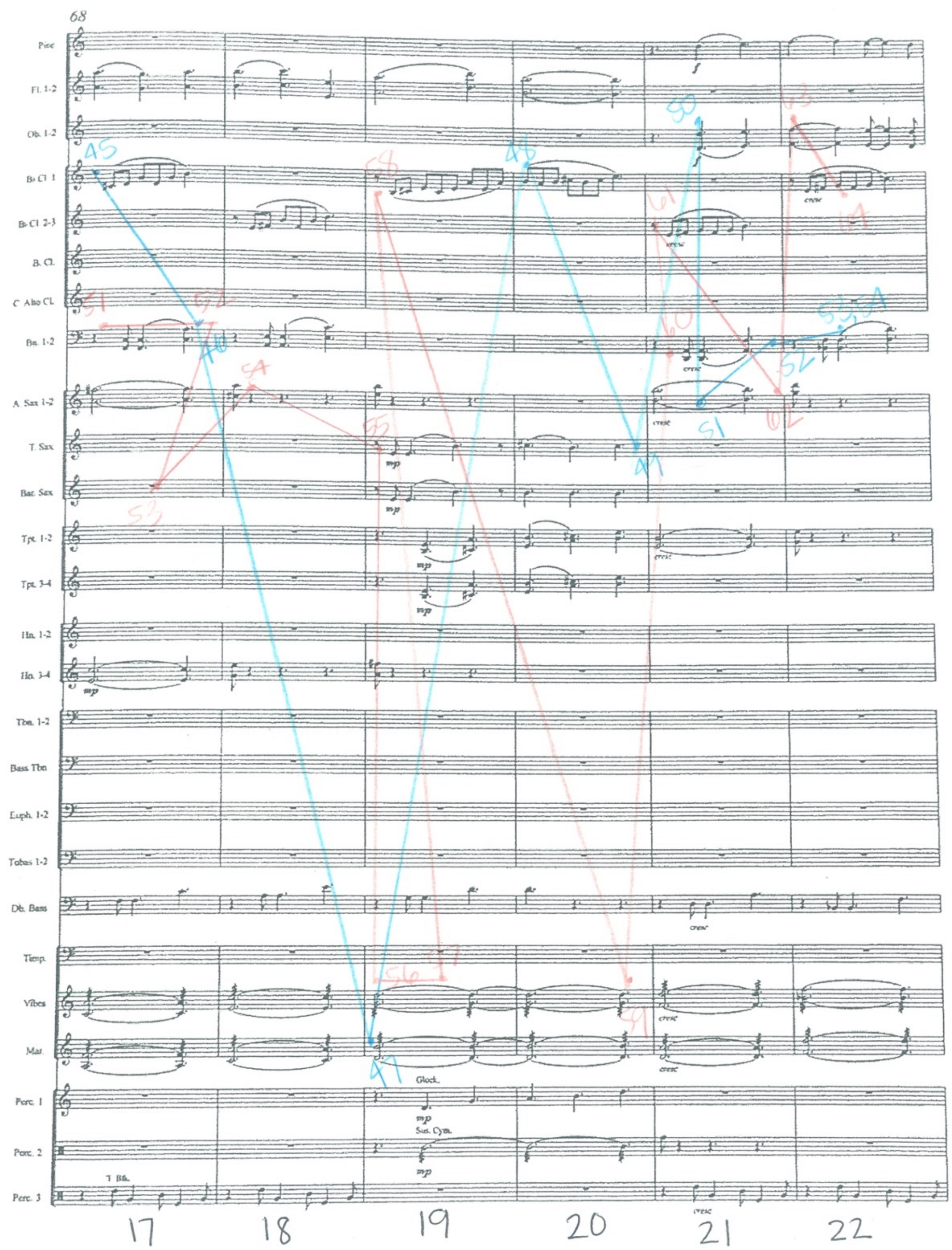
F1


54
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Glock.
Perc. 1
Sus. Cym.
Perc. 2
Perc. 3
3 4 5 6 7 8 9 10

F1



62
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Glock.
Perc. 2
Sus. Cym.
Perc. 3
T. Blk.
11
12
13
14
15
16


68
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
T. Bk.
17
18
19
20
21
22

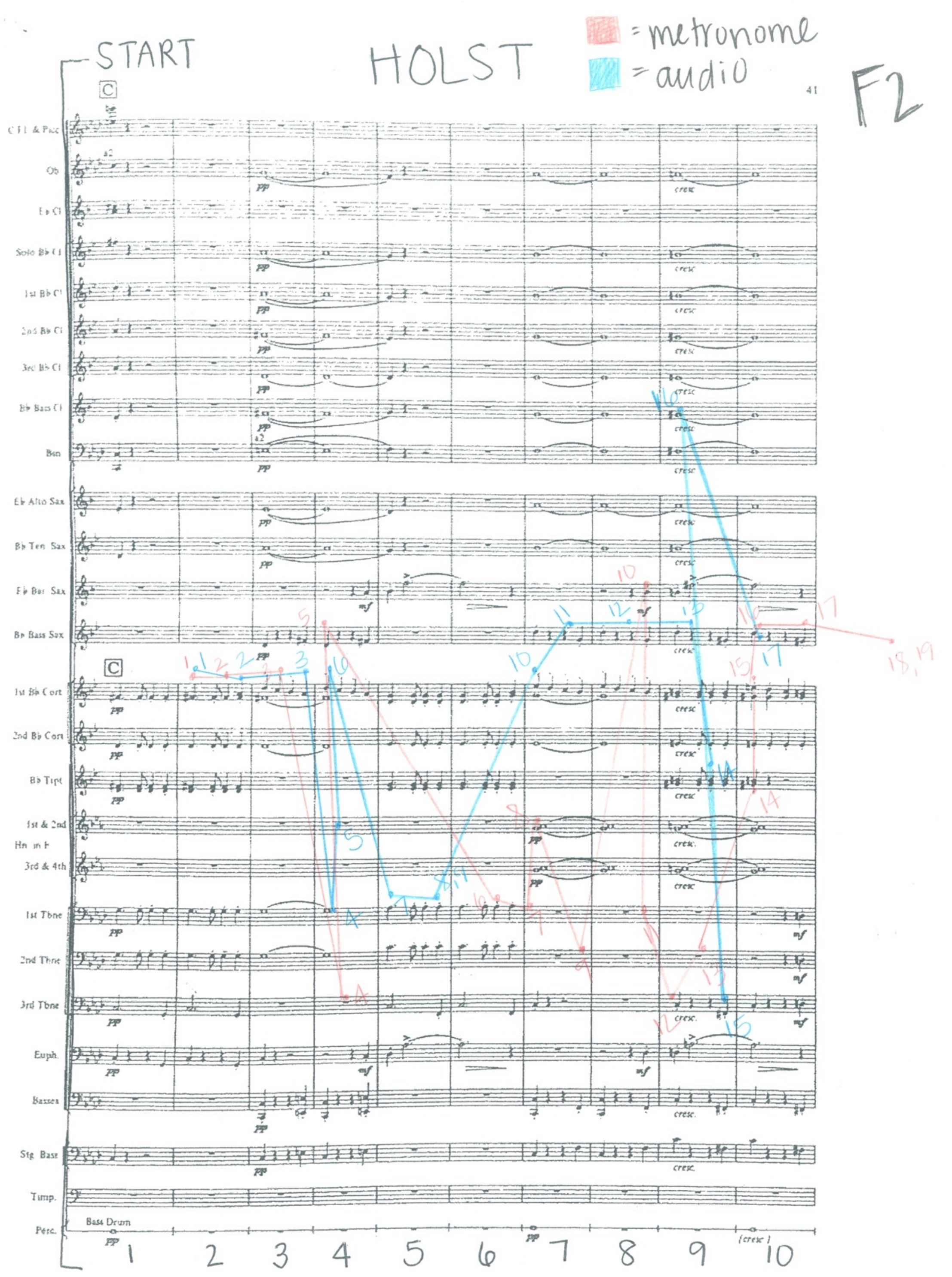
F1

14

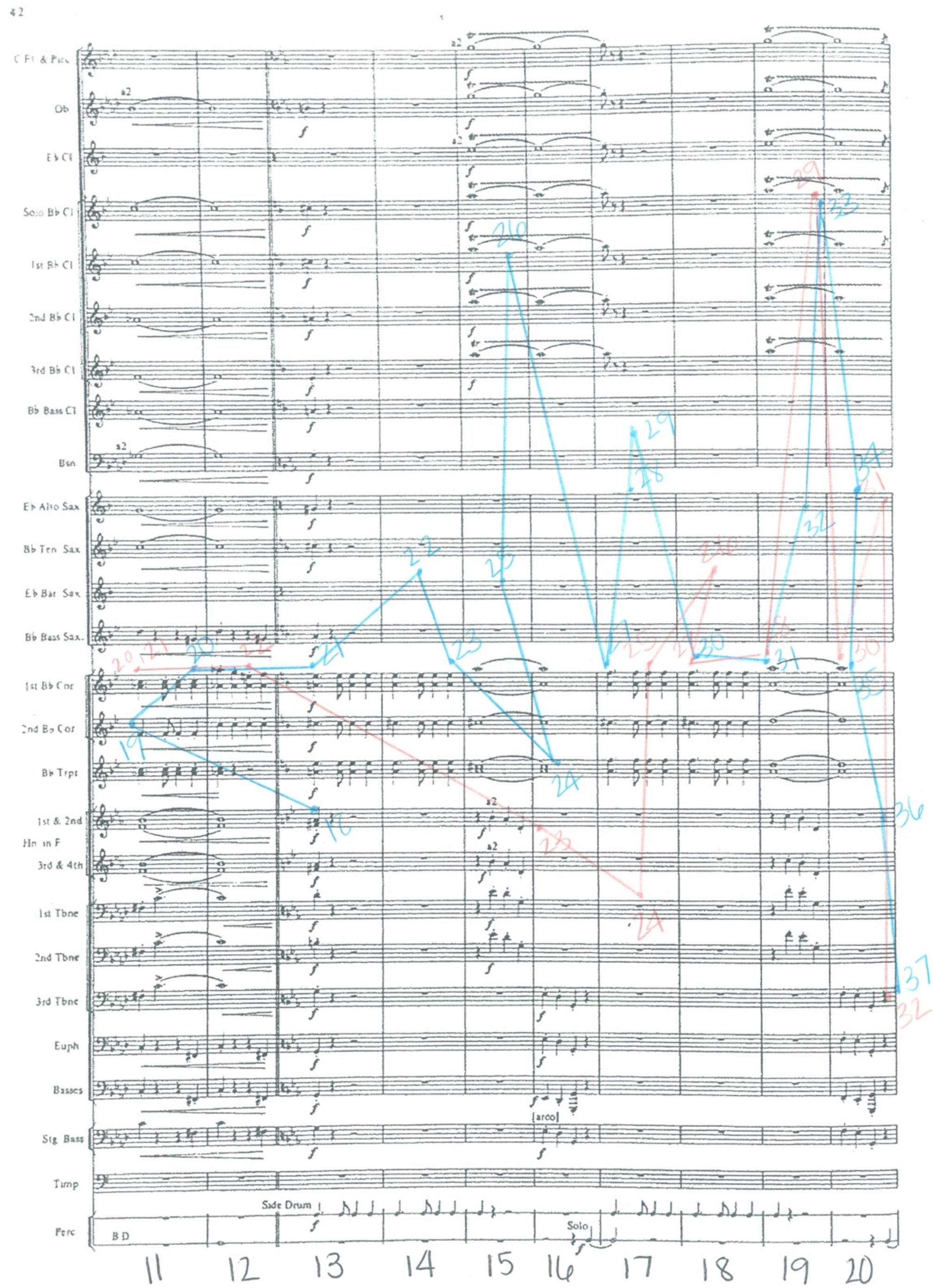
74
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
E♭ Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Sus. Cym.
mp cresc.
23
24
25
26
27
28

FI

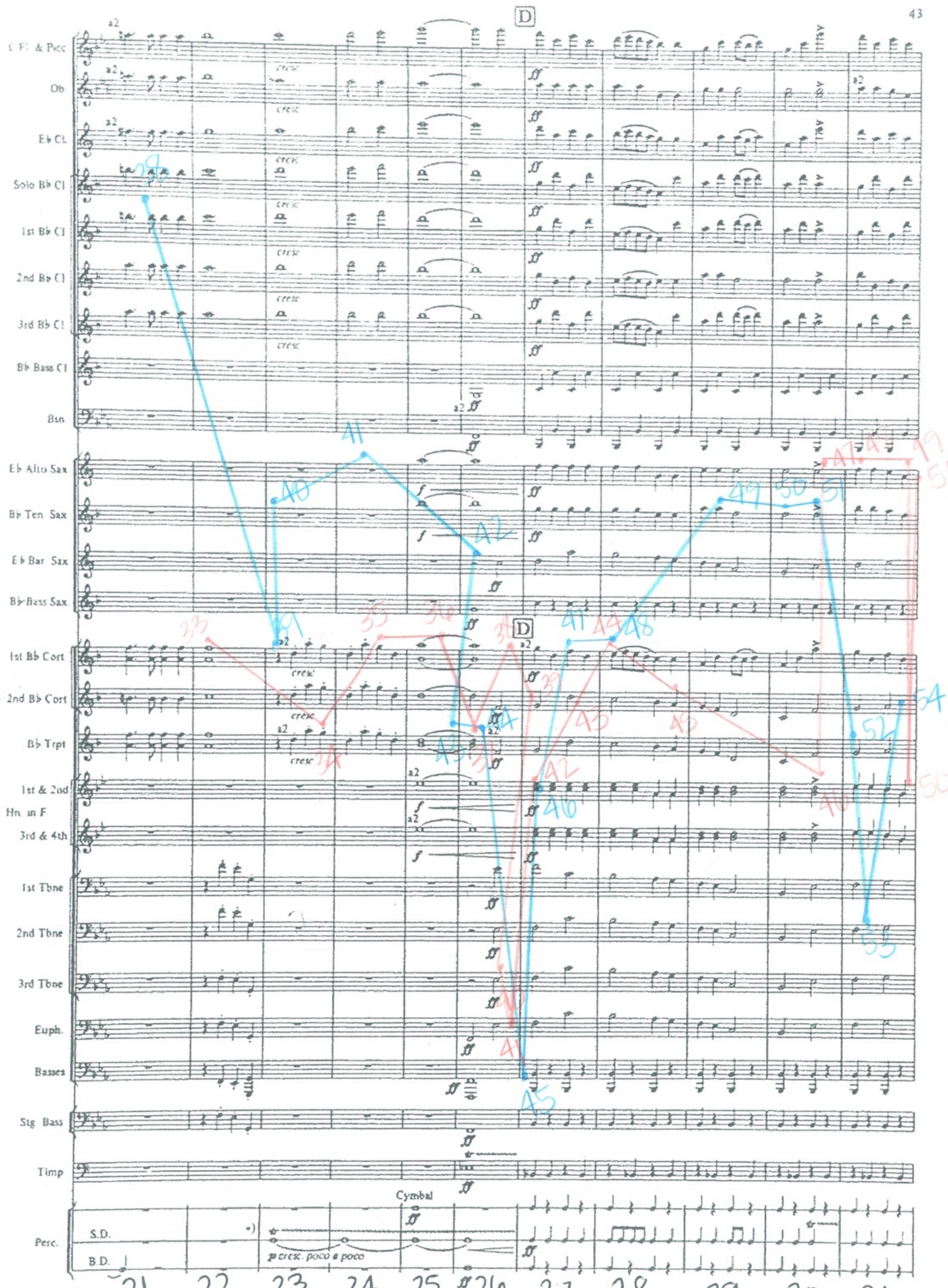

15
END
80
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
E♭ Alto Cl.
Bn. 1-2
A. Sax. 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym
Chimes
Toms
29
30
31


START
HOLST
= metronome
= audio
41
F2
C
C Fl. & Picc.
Ob.
E♭ Cl.
Solo B♭ Cl.
1st B♭ Cl.
2nd B♭ Cl.
3rd B♭ Cl.
B♭ Bass Cl.
Bsn.
E♭ Alto Sax.
B♭ Ten. Sax.
E♭ Bar. Sax.
B♭ Bass Sax.
1st B♭ Cort.
2nd B♭ Cort.
B♭ Tpt.
1st & 2nd
Hn. in F
3rd & 4th
1st Tbne.
2nd Tbne.
3rd Tbne.
Euph.
Basses
Stg. Bass
Timp.
Perc.
Bass Drum
pp
mf
cresc.
1 2 3 4 5 6 7 8 9 10

F2

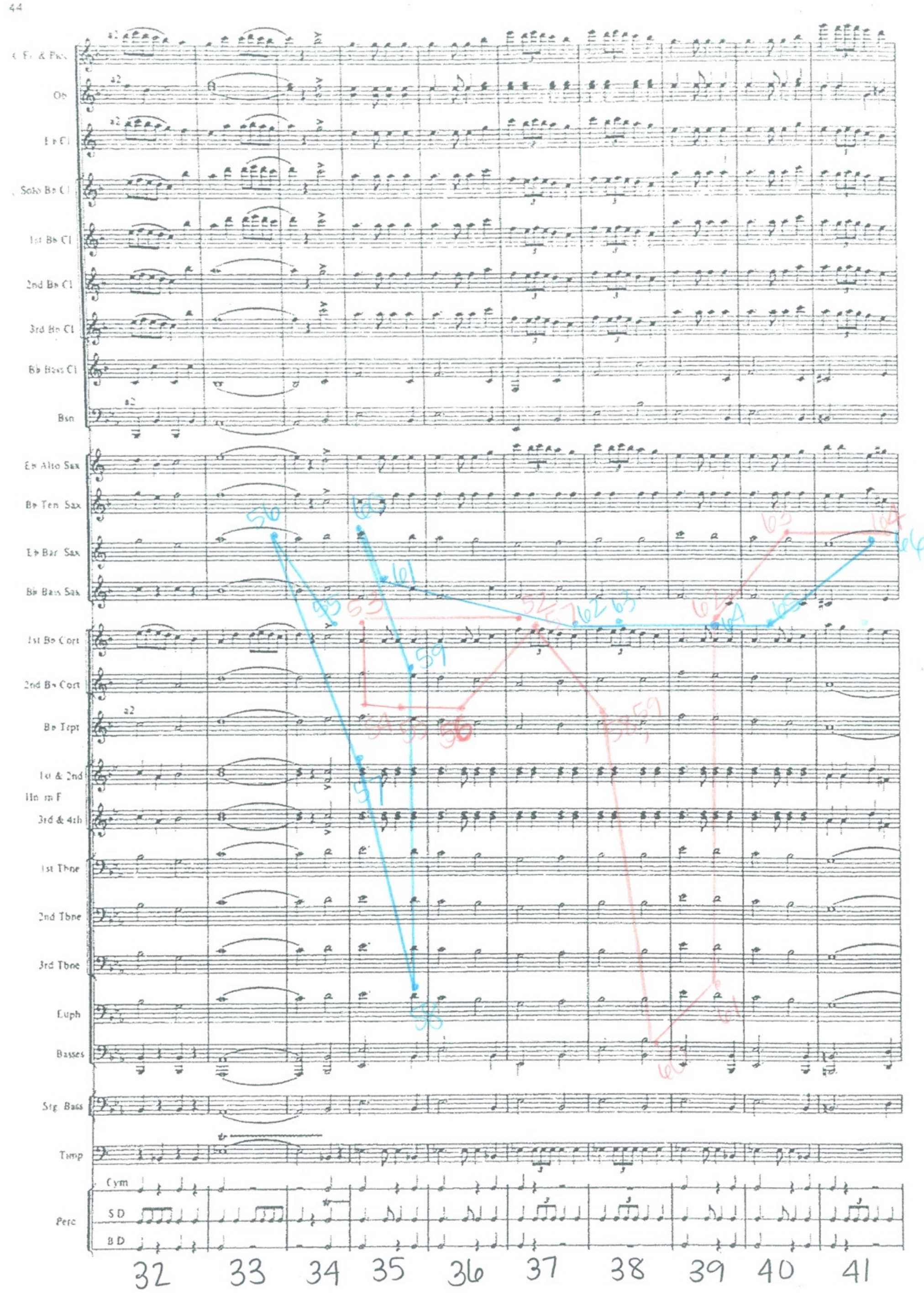

42
C Fl & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax.
1st Bb Cor
2nd Bb Cor
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Perc
Side Drum
B D
Solo
[arco]
a2
11
12
13
14
15
16
17
18
19
20

F2



*) From here to the end extra side drums may be introduced *ad lib.*, all playing this part

F2


44
C Fl & Picc
Ob
E♭ Cl
Solo B♭ Cl
1st B♭ Cl
2nd B♭ Cl
3rd B♭ Cl
B♭ Bass Cl
Bsn
E♭ Alto Sax
B♭ Ten Sax
E♭ Bar Sax
B♭ Bass Sax
1st B♭ Cort
2nd B♭ Cort
B♭ Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Perc
Cym
SD
BD
32
33
34
35
36
37
38
39
40
41

F2

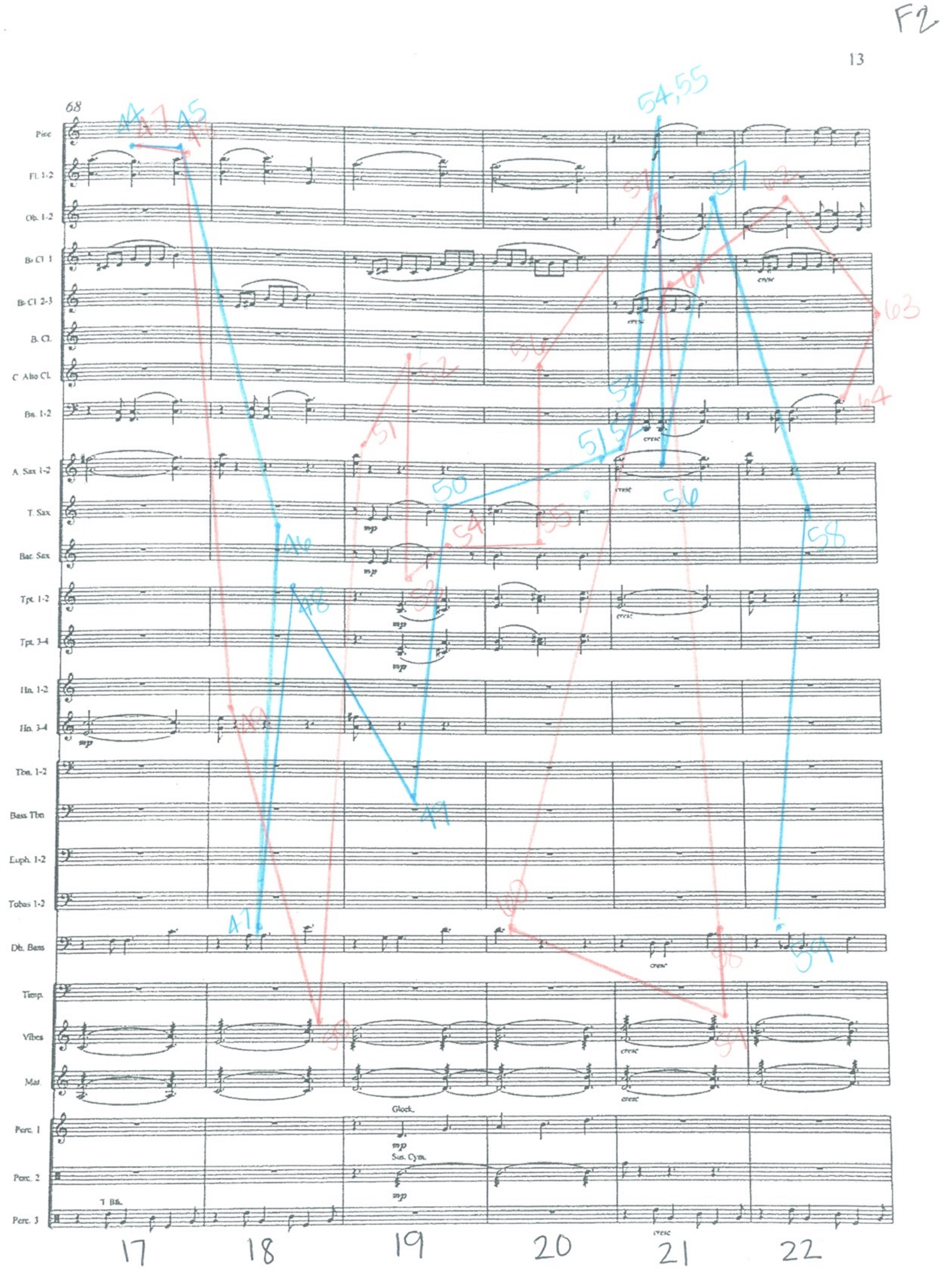

END
45
C Fl. & Picc
Ob
E♭ Cl
Solo B♭ Cl.
1st B♭ Cl
2nd B♭ Cl
3rd B♭ Cl
B♭ Bass Cl
Bsn
E♭ Alto Sax
B♭ Ten Sax
E♭ Bar Sax
B♭ Bass Sax
1st B♭ Cort
2nd B♭ Cort
B♭ Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph.
Basses
Stg. Bass
Timp
Perc
Cym
S.D.
B.D
cresc. poco a poco
ff
42
43

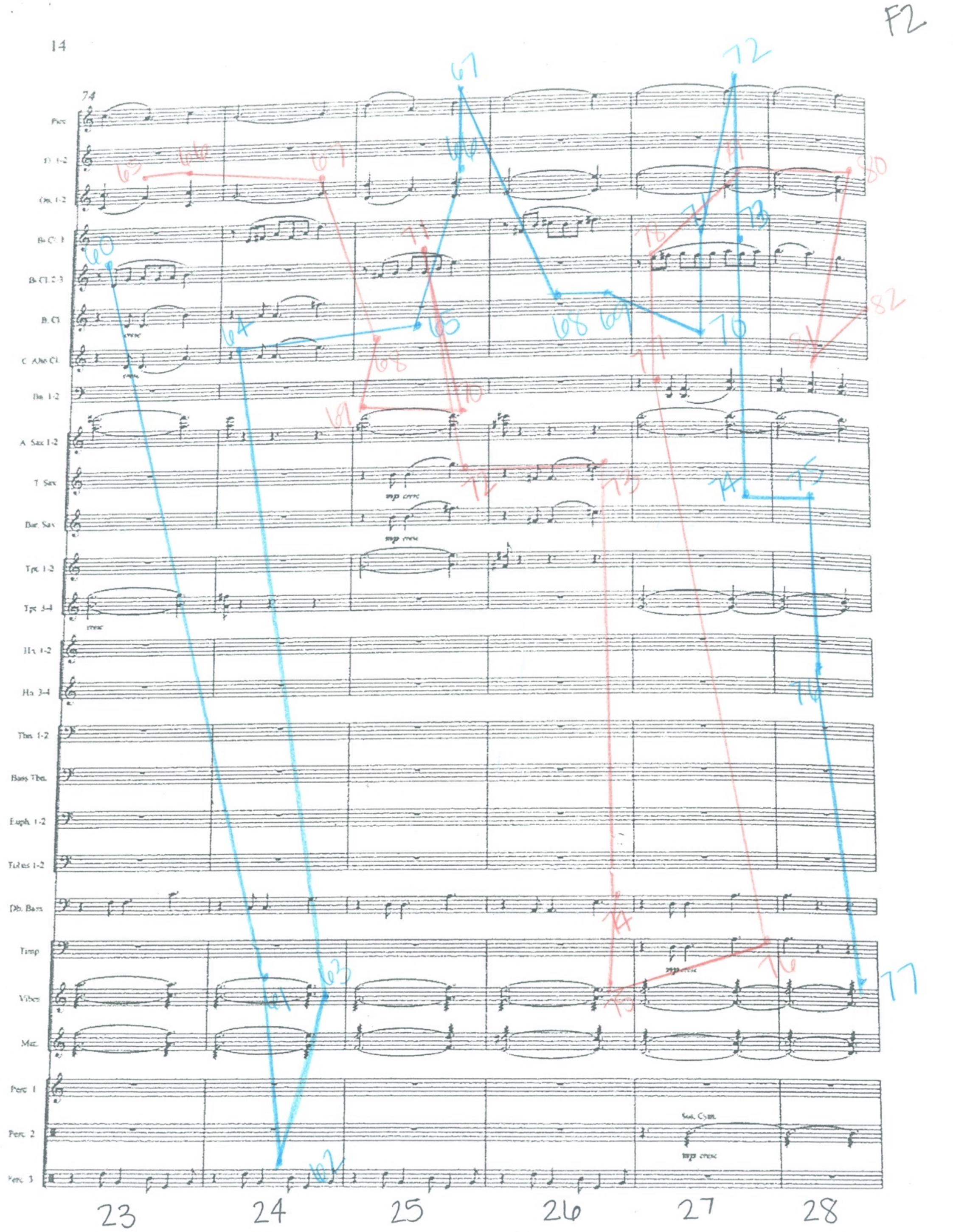

= metronome
= audio
EWAZEN
START
F2
10
48
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Toms
Glock.
Sus. Cym.
1
2

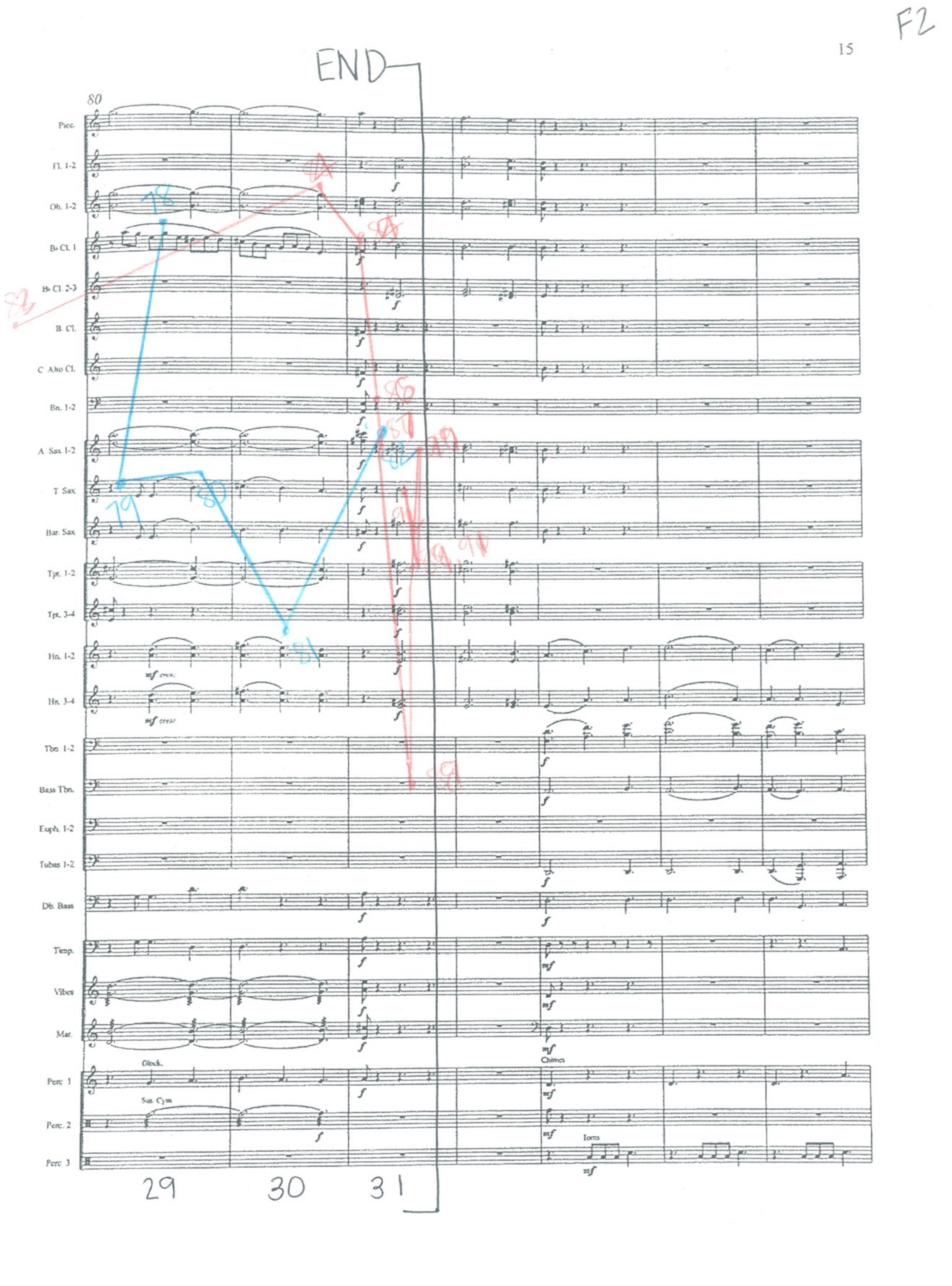
F2

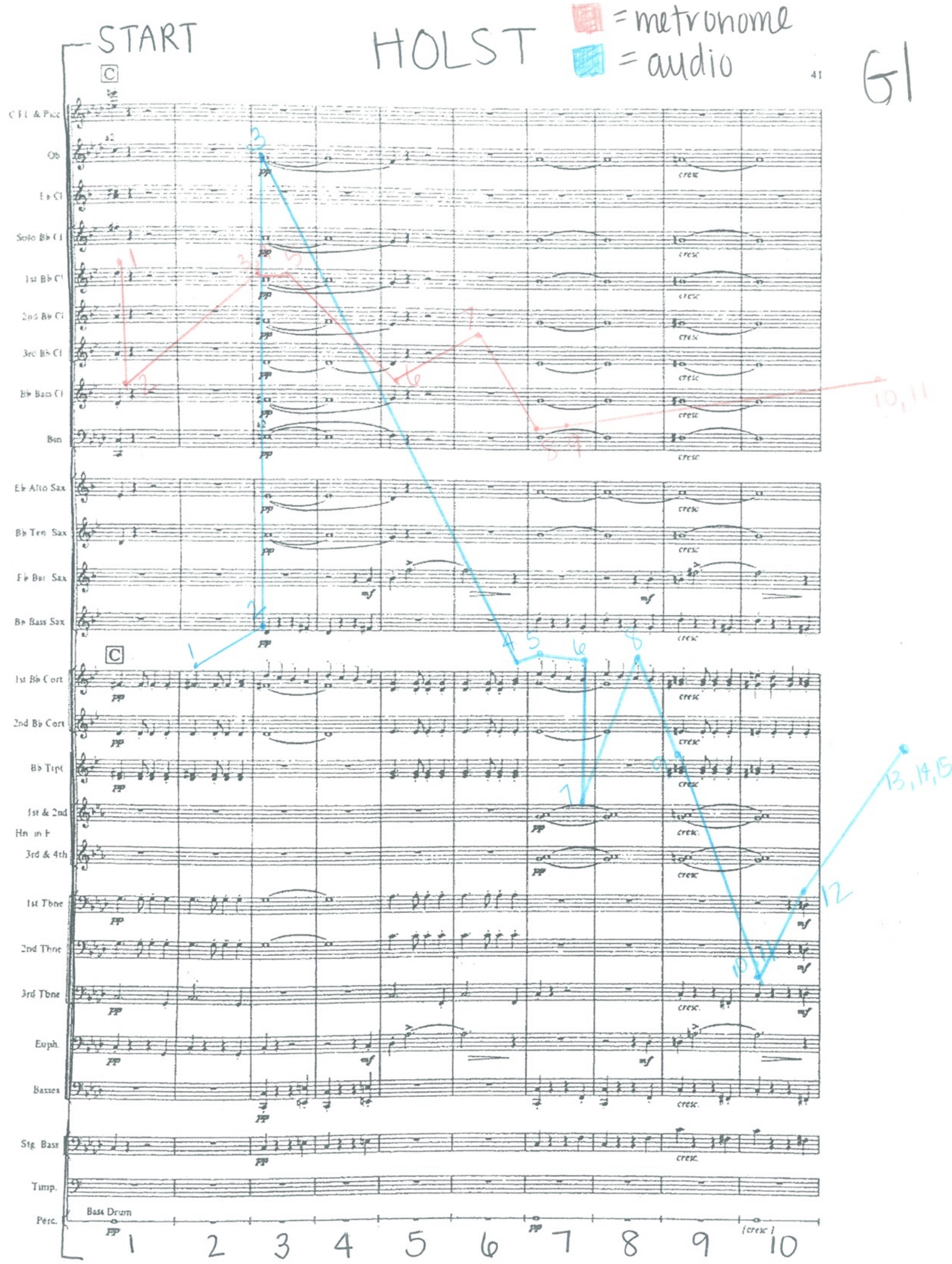

54
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Glock.
Perc. 2
Sus. Cym.
Perc. 3
3
4
5
6
7
8
9
10


F2
12
62
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Glock.
Perc. 2
Sus. Cym.
Perc. 3
T. Blk.
11
12
13
14
15
16

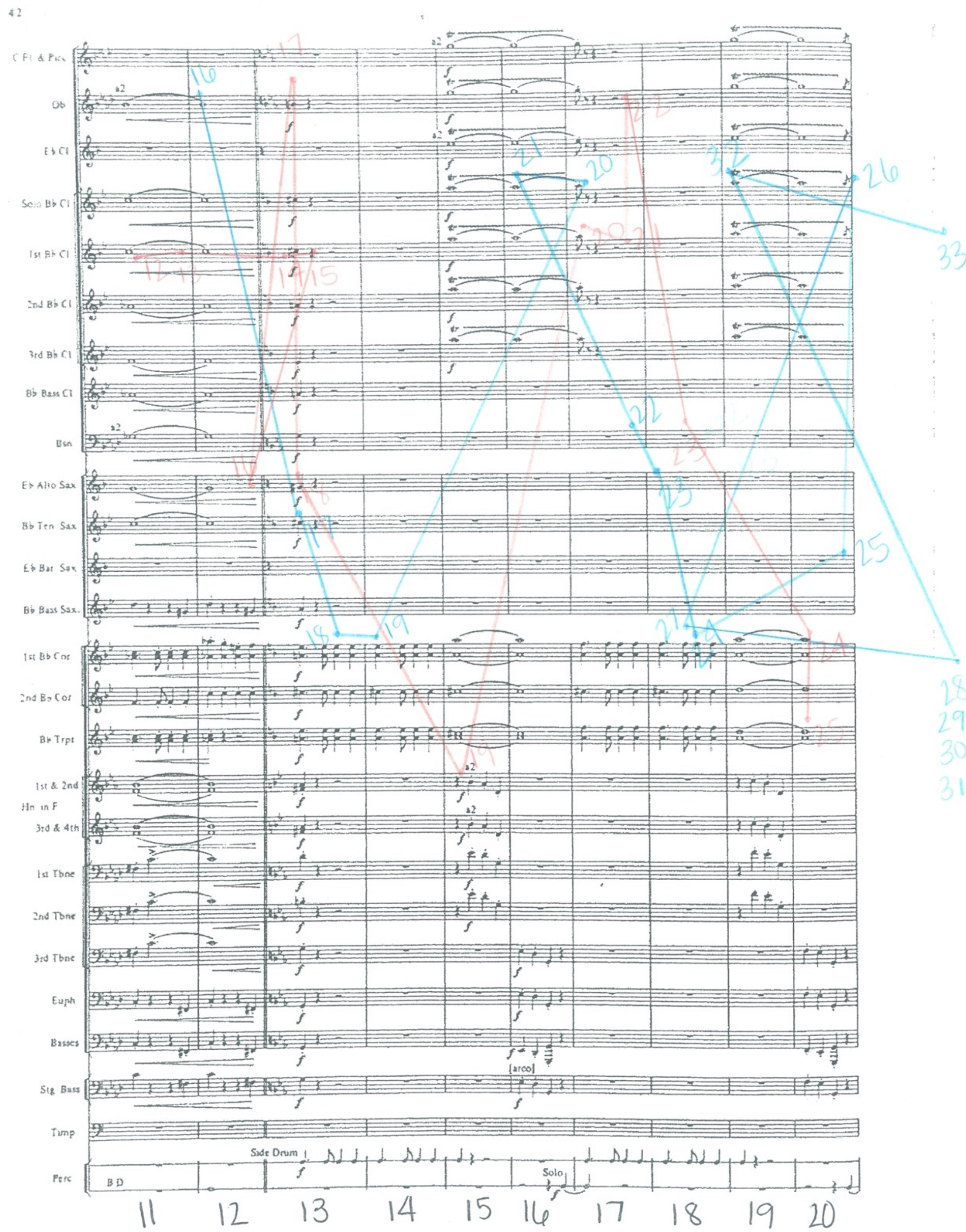

F2
13
68
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
T. Bl.
mp
cresc
17
18
19
20
21
22


F2
14
74
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Sus. Cym.
mp cresc
23
24
25
26
27
28


F2
15
END
80
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C Alto Cl.
Bn. 1-2
A. Sax. 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym
Chimes
Toms
29
30
31


START
HOLST
= metronome
= audio
G1
41
C
C Fl. & Picc.
Ob.
E♭ Cl.
Solo B♭ Cl.
1st B♭ Cl.
2nd B♭ Cl.
3rd B♭ Cl.
B♭ Bass Cl.
Bsn.
E♭ Alto Sax.
B♭ Ten. Sax.
E♭ Bar. Sax.
B♭ Bass Sax.
1st B♭ Cort.
2nd B♭ Cort.
B♭ Tpt.
1st & 2nd
Hn. in F
3rd & 4th
1st Tbne.
2nd Tbne.
3rd Tbne.
Euph.
Basses
Stg. Bass
Timp.
Perc.
Bass Drum
10, 11
13, 14, 15
1 2 3 4 5 6 7 8 9 10

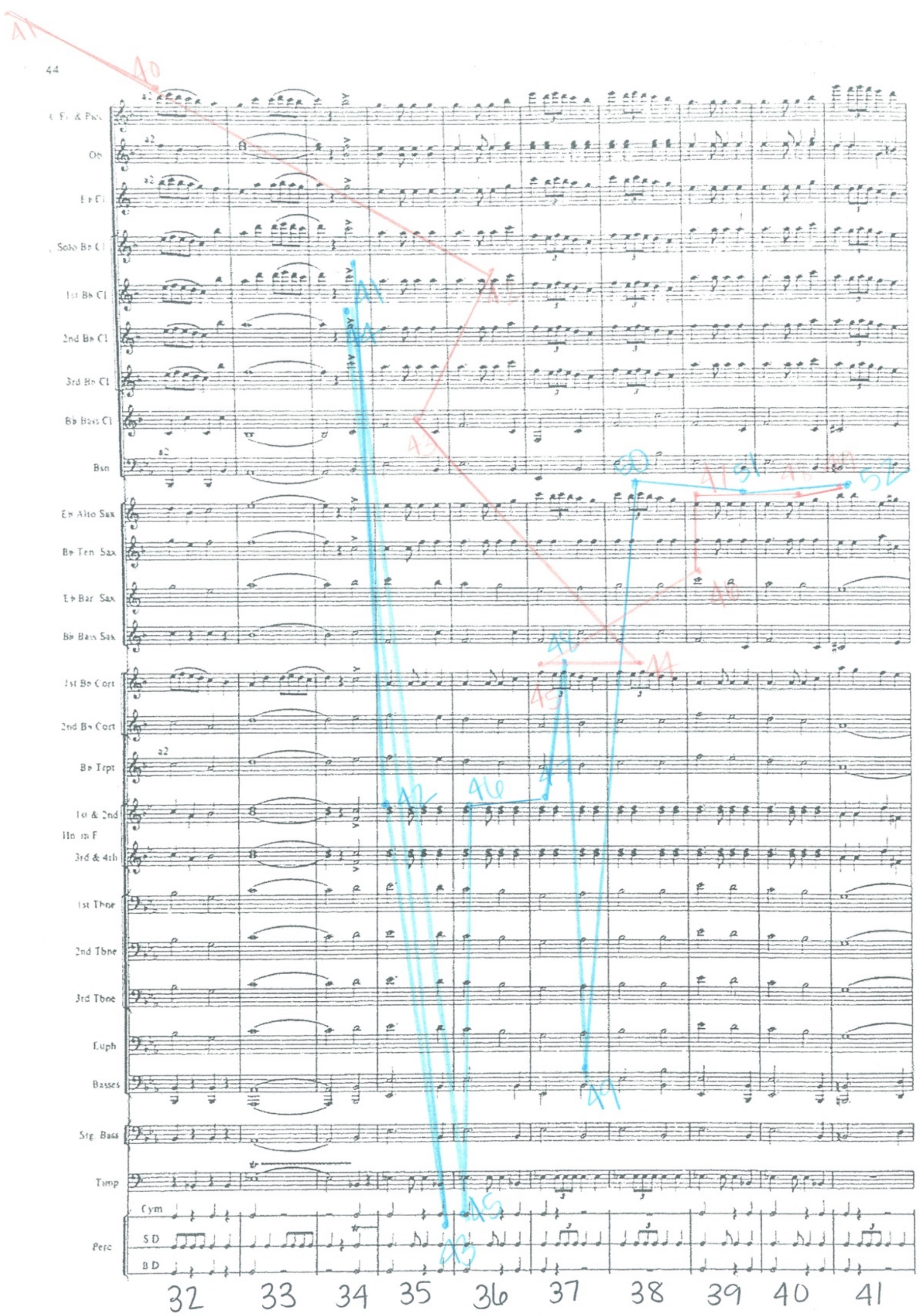
G1


42
C Fl & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cor
2nd Bb Cor
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Perc
Side Drum
Solo
(arco)
B D
11 12 13 14 15 16 17 18 19 20

G1

*) From here to the end extra side drums may be introduced *ad lib.*, all playing this part

G1

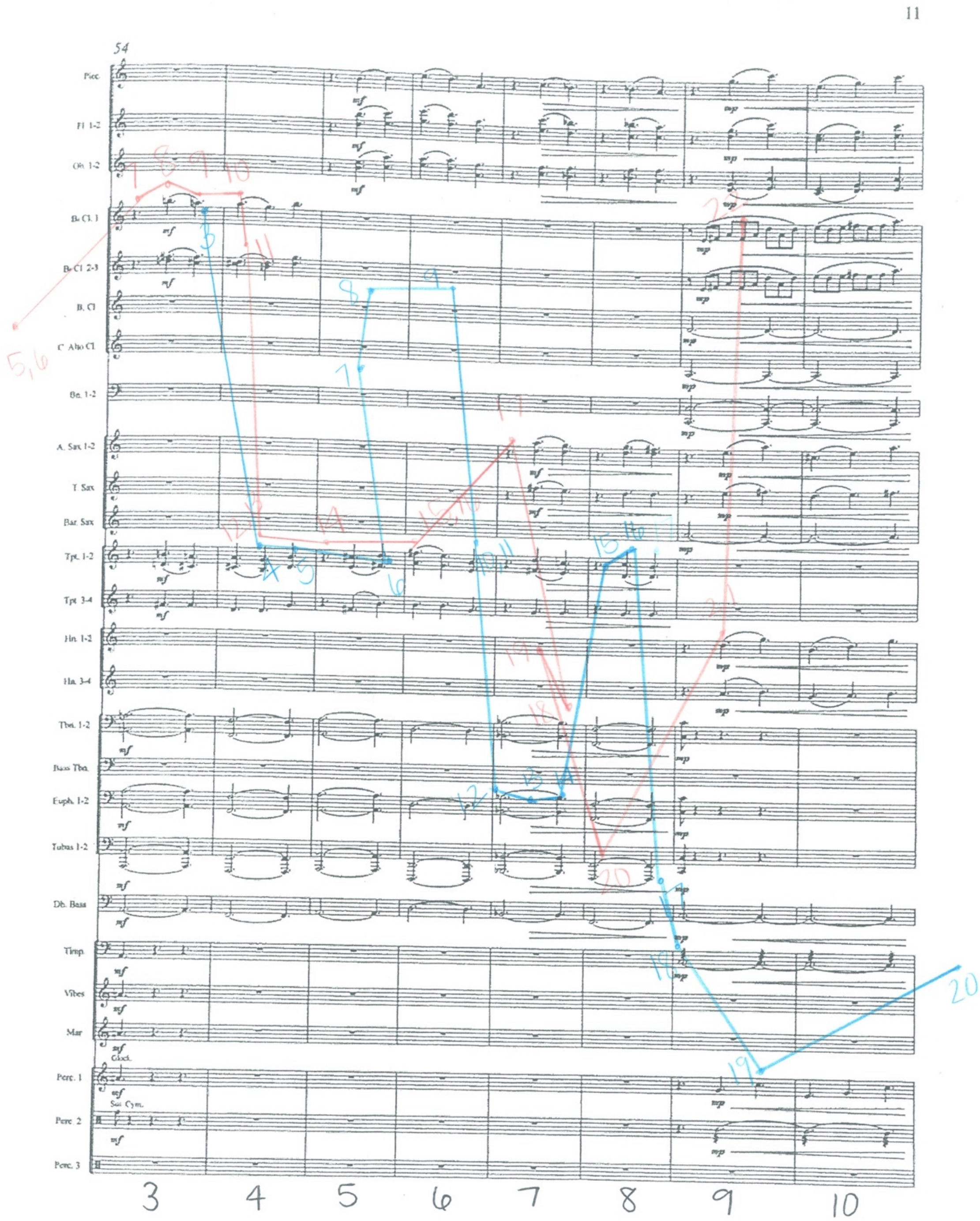

44
C Fl. & Picc.
Ob.
E♭ Cl.
Solo B♭ Cl.
1st B♭ Cl.
2nd B♭ Cl.
3rd B♭ Cl.
B♭ Bass Cl.
Bsn.
E♭ Alto Sax.
B♭ Ten. Sax.
E♭ Bar. Sax.
B♭ Bass Sax.
1st B♭ Cort.
2nd B♭ Cort.
B♭ Tpt.
1st & 2nd
Hn. in F
3rd & 4th
1st Tbne.
2nd Tbne.
3rd Tbne.
Euph.
Basses
Str. Bass
Timp.
Cym.
S.D.
B.D.
Perc.
32
33
34
35
36
37
38
39
40
41

G1

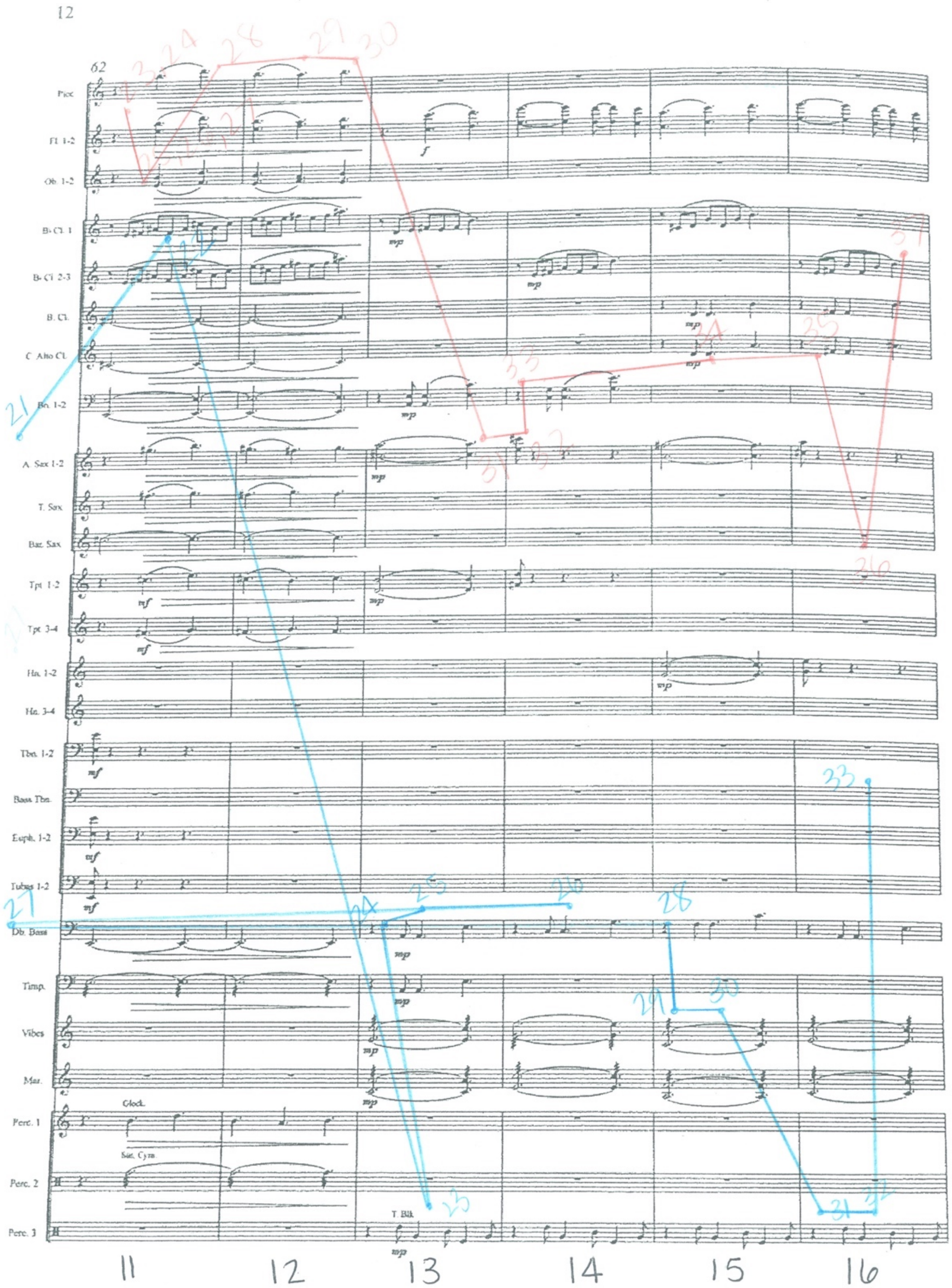

END
45
C Fl. & Pic.
Ob.
Eb Cl.
Solo Bb Cl.
1st Bb Cl.
2nd Bb Cl.
3rd Bb Cl.
Bb Bass Cl.
Bsn.
Eb Alto Sax.
Bb Ten. Sax.
Eb Bar. Sax.
Bb Bass Sax.
1st Bb Cort.
2nd Bb Cort.
Bb Trpt.
1st & 2nd
Hn. in F
3rd & 4th
1st Tbne.
2nd Tbne.
3rd Tbne.
Euph.
Basses
Stg. Bass
Timp.
Cym.
Perc.
S.D.
B.D.
a2
cresc. poco a poco
51
52
53
54
42
43

10
= metronome
= audio
EWAZEN
START
G1
48
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Glock.
Perc 1
Sus. Cym.
Perc 2
Toms
Perc 3
1
2

G1


11
54
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Glock.
Perc. 1
Sus. Cym.
Perc. 2
Perc. 3
3 4 5 6 7 8 9 10

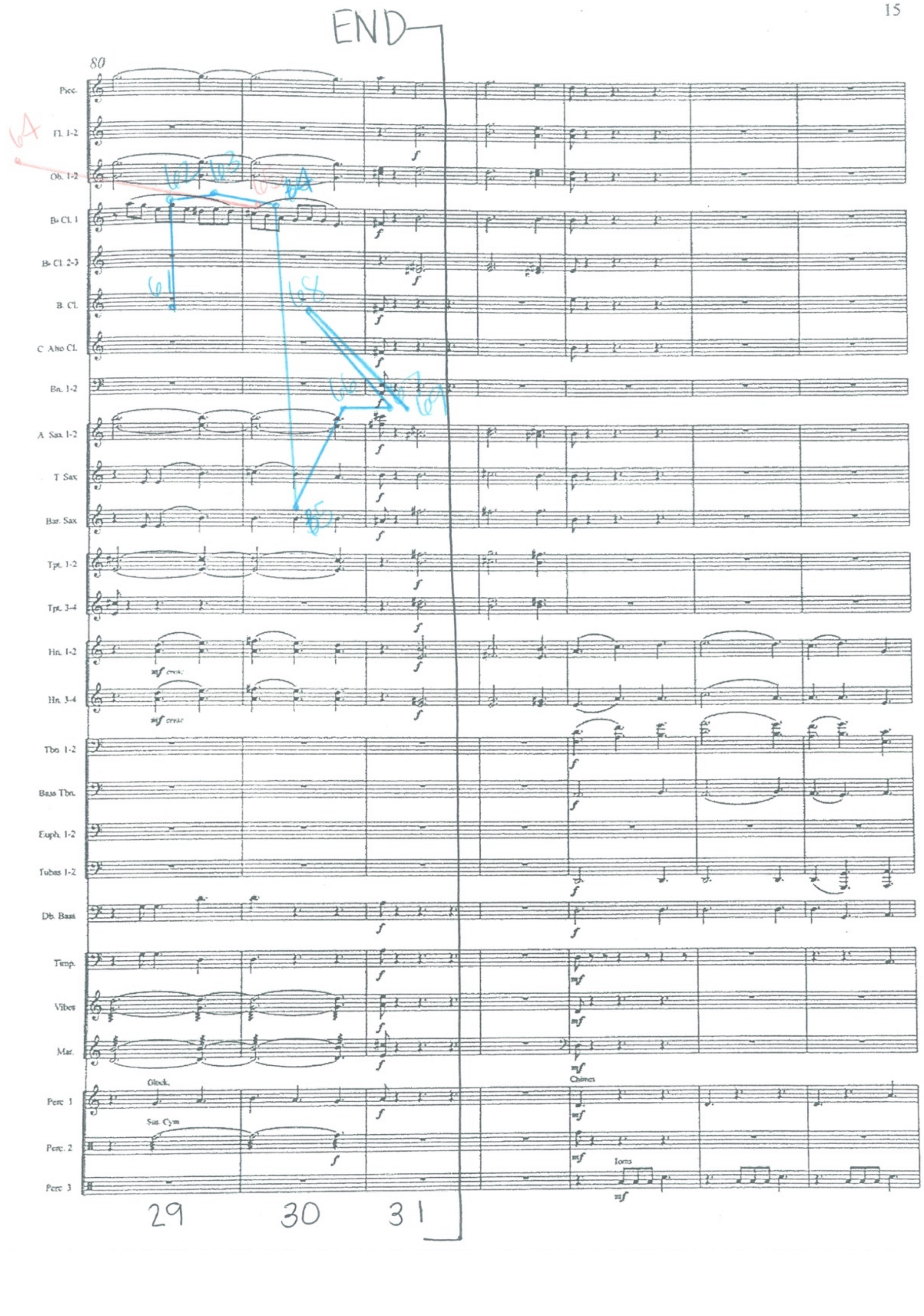
G1


12
62
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt 1-2
Tpt 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Glock.
Perc. 2
Sus. Cym.
Perc. 3
T. Blk.
11
12
13
14
15
16


G1
13
68
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
T. Bl.
17
18
19
20
21
22

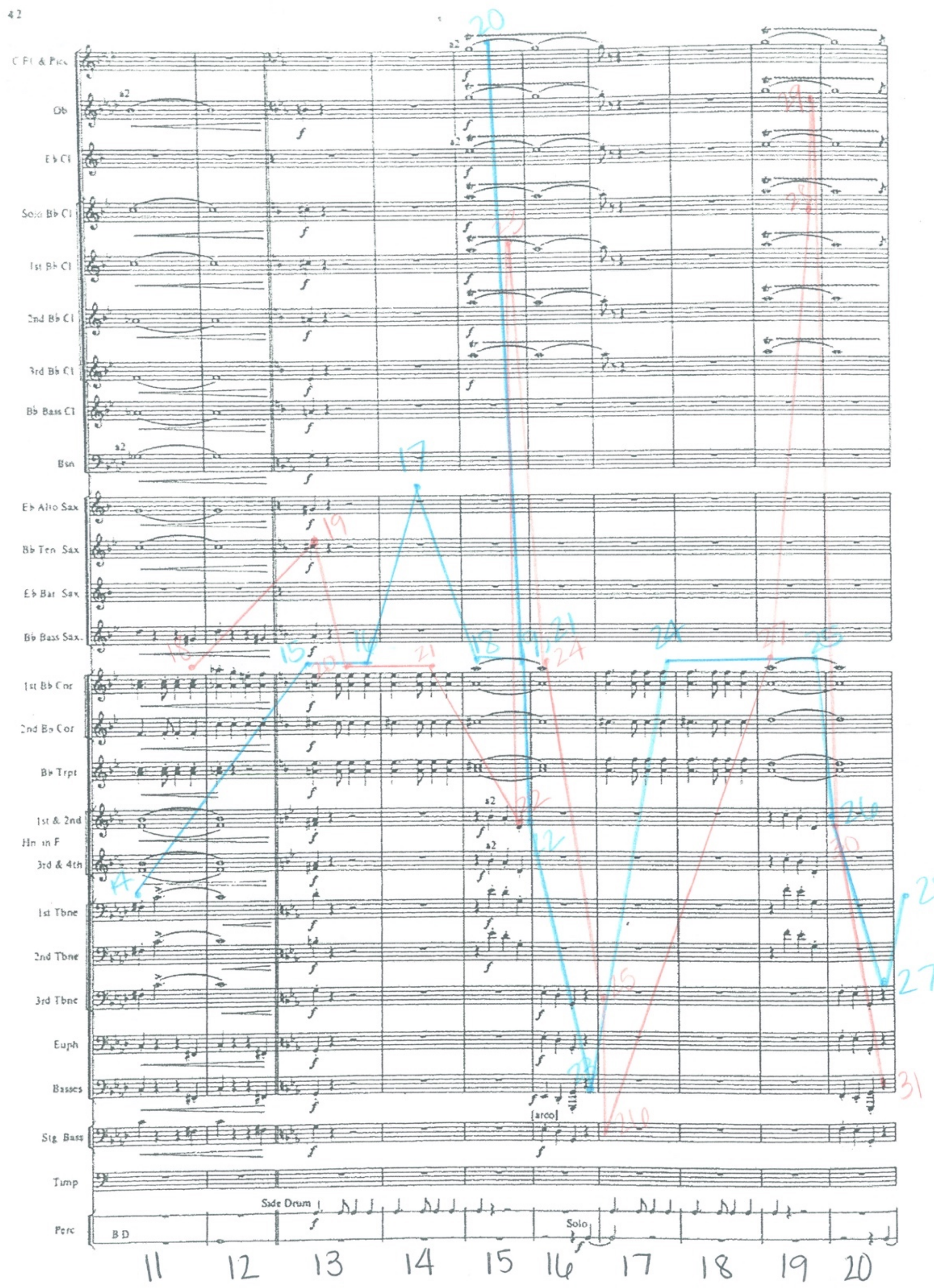
G1


74
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
cresc.
mp cresc.
Sus. Cym.
23
24
25
26
27
28

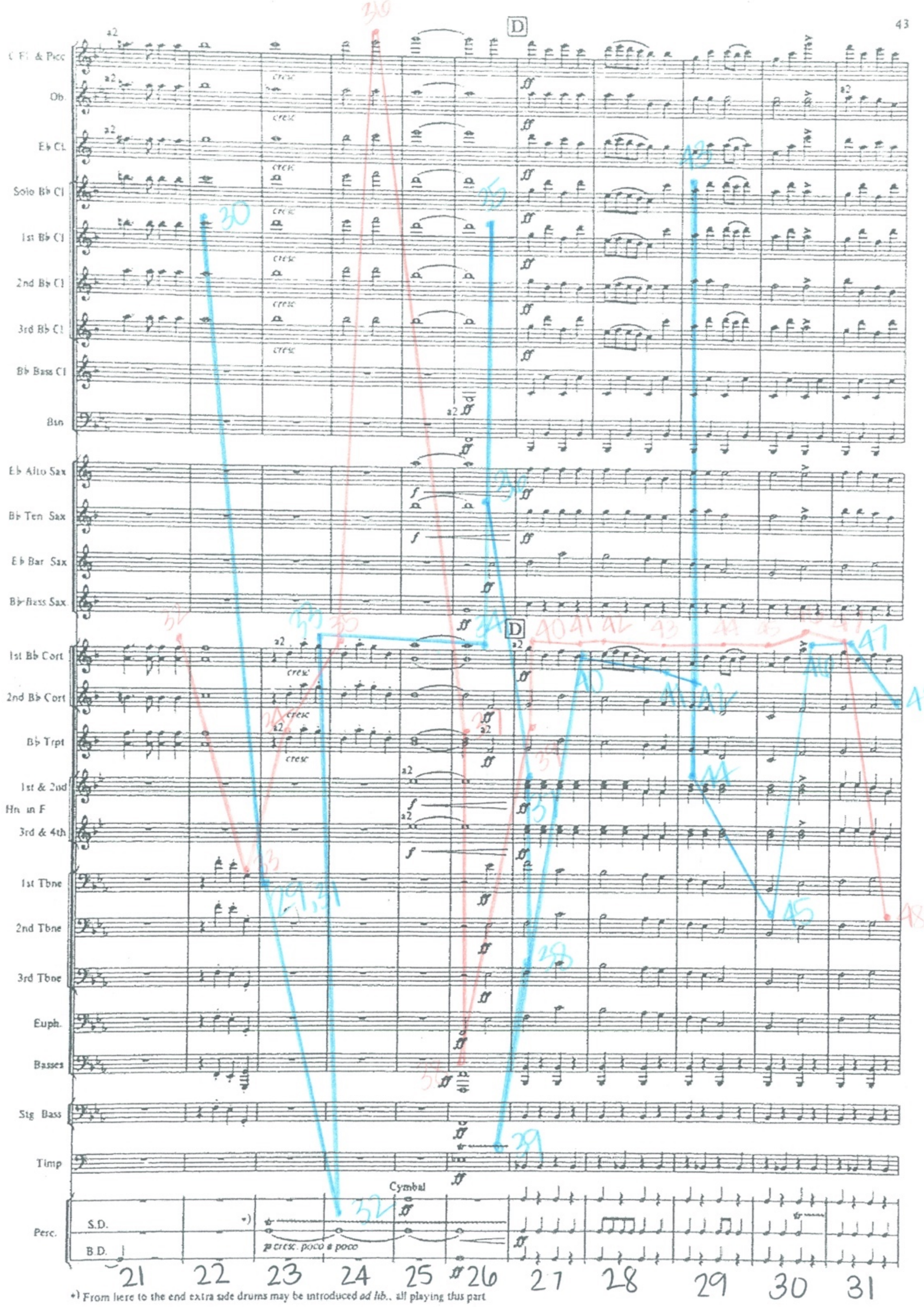

END
80
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
Chimes
Toms
29
30
31


START
HOLST
= metronome
= audio
41
G2
(old G3)
C
C Fl. & Picc.
Ob.
E♭ Cl.
Solo B♭ Cl.
1st B♭ Cl.
2nd B♭ Cl.
3rd B♭ Cl.
B♭ Bass Cl.
Bsn.
E♭ Alto Sax.
B♭ Ten. Sax.
E♭ Bar. Sax.
B♭ Bass Sax.
1st B♭ Cort.
2nd B♭ Cort.
B♭ Tpt.
1st & 2nd
Hn. in F
3rd & 4th
1st Tbne.
2nd Tbne.
3rd Tbne.
Euph.
Basses
Stg. Bass
Timp.
Perc.
Bass Drum
cresc.
1 2 3 4 5 6 7 8 9 10

G2

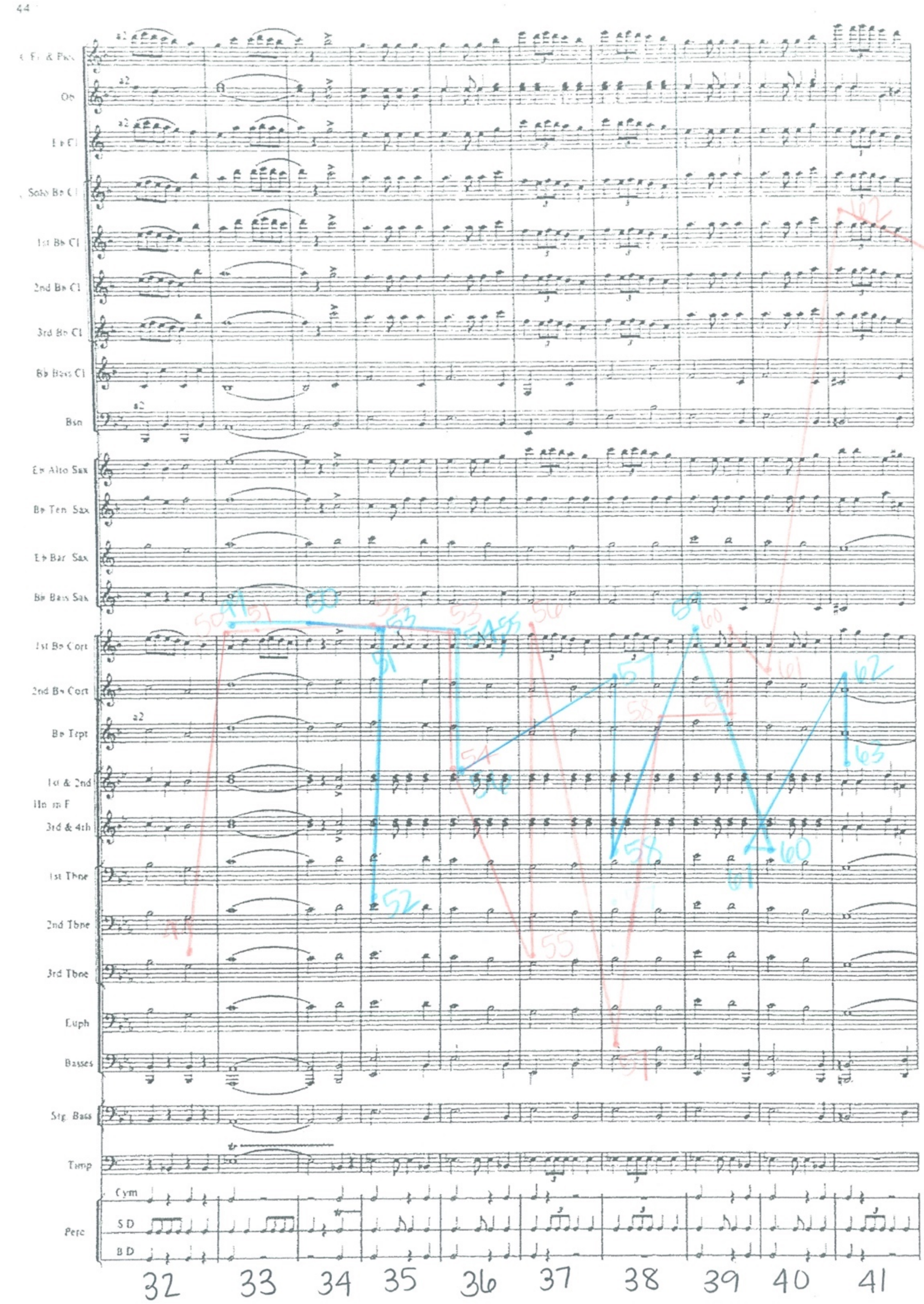

42
C Fl & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cor
2nd Bb Cor
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Perc
Side Drum
BD
Solo
[arco]
a2
11
12
13
14
15
16
17
18
19
20

G2

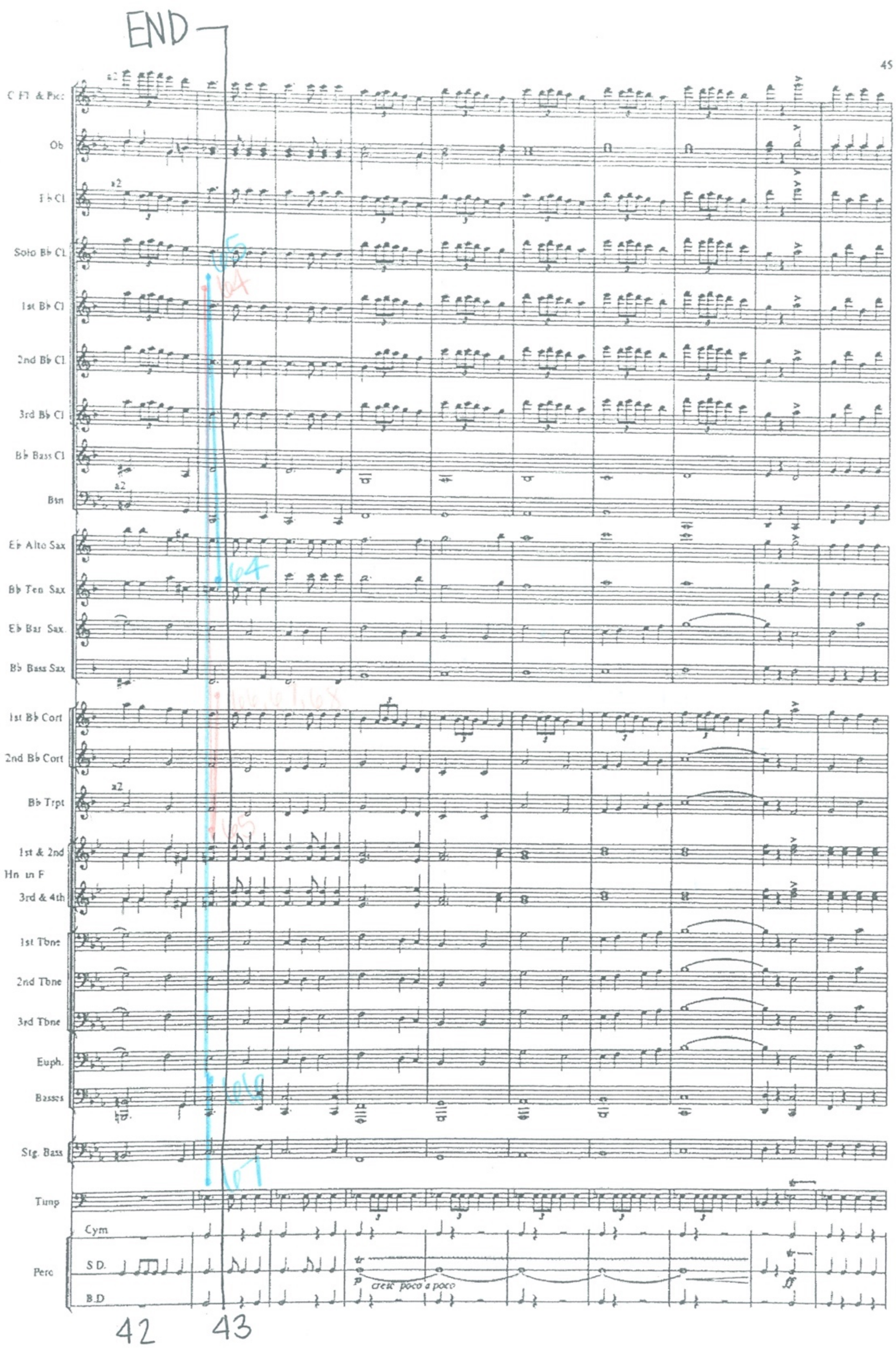


*) From here to the end extra side drums may be introduced *ad lib.*, all playing this part

G2


44
Fl & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cort
2nd Bb Cort
Bb Tpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Cym
SD
BD
Perc
32
33
34
35
36
37
38
39
40
41

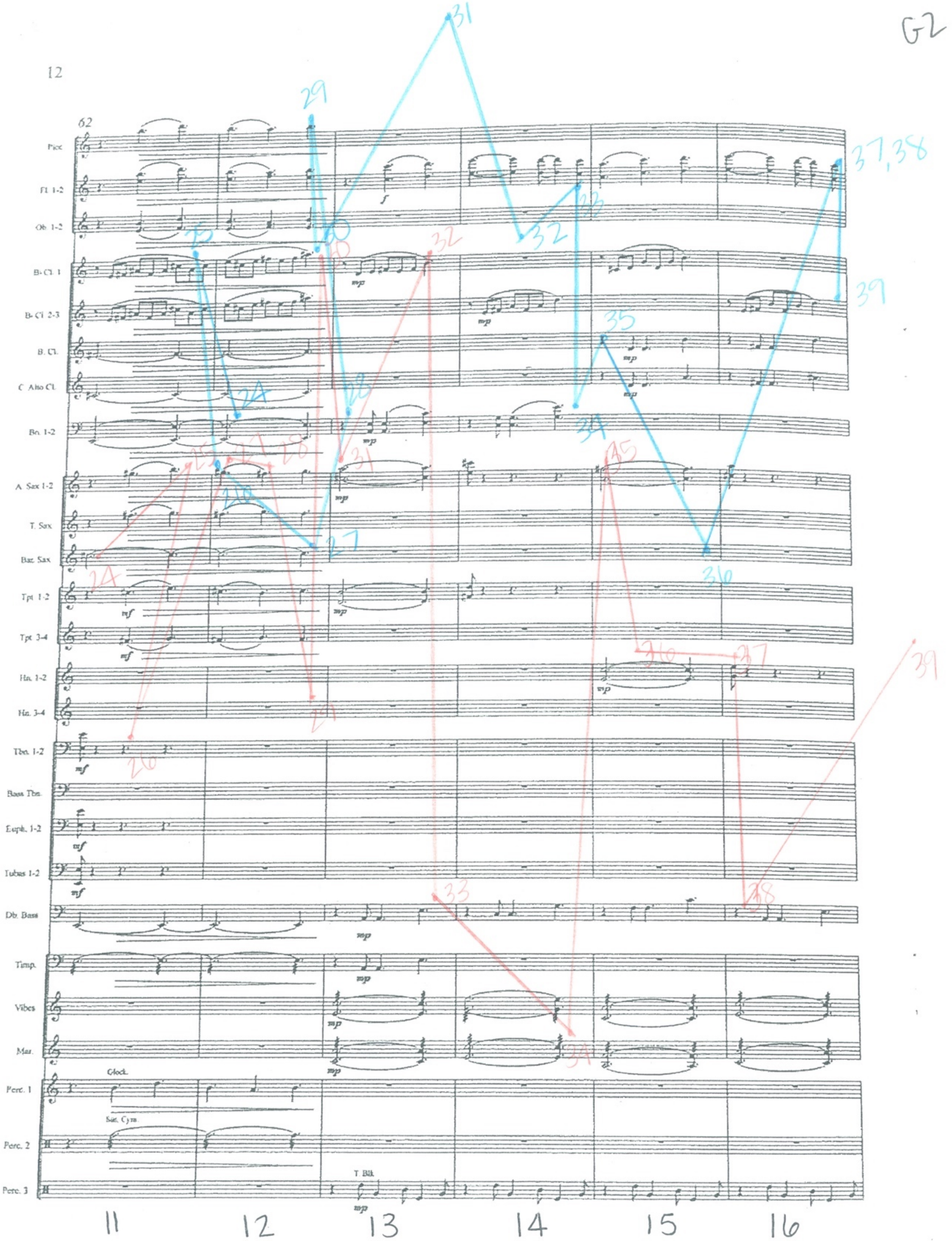
62


END
45
C Fl. & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cort
2nd Bb Cort
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph.
Basses
Stg. Bass
Timp
Cym
S.D.
B.D.
Perc
cresc poco a poco
42
43


= metronome
= audio
EWAZEN
START
G2
(old G3)
48
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc 1
Perc 2
Perc 3
Toms
Glock.
Sus. Cym.
1
2
3
4

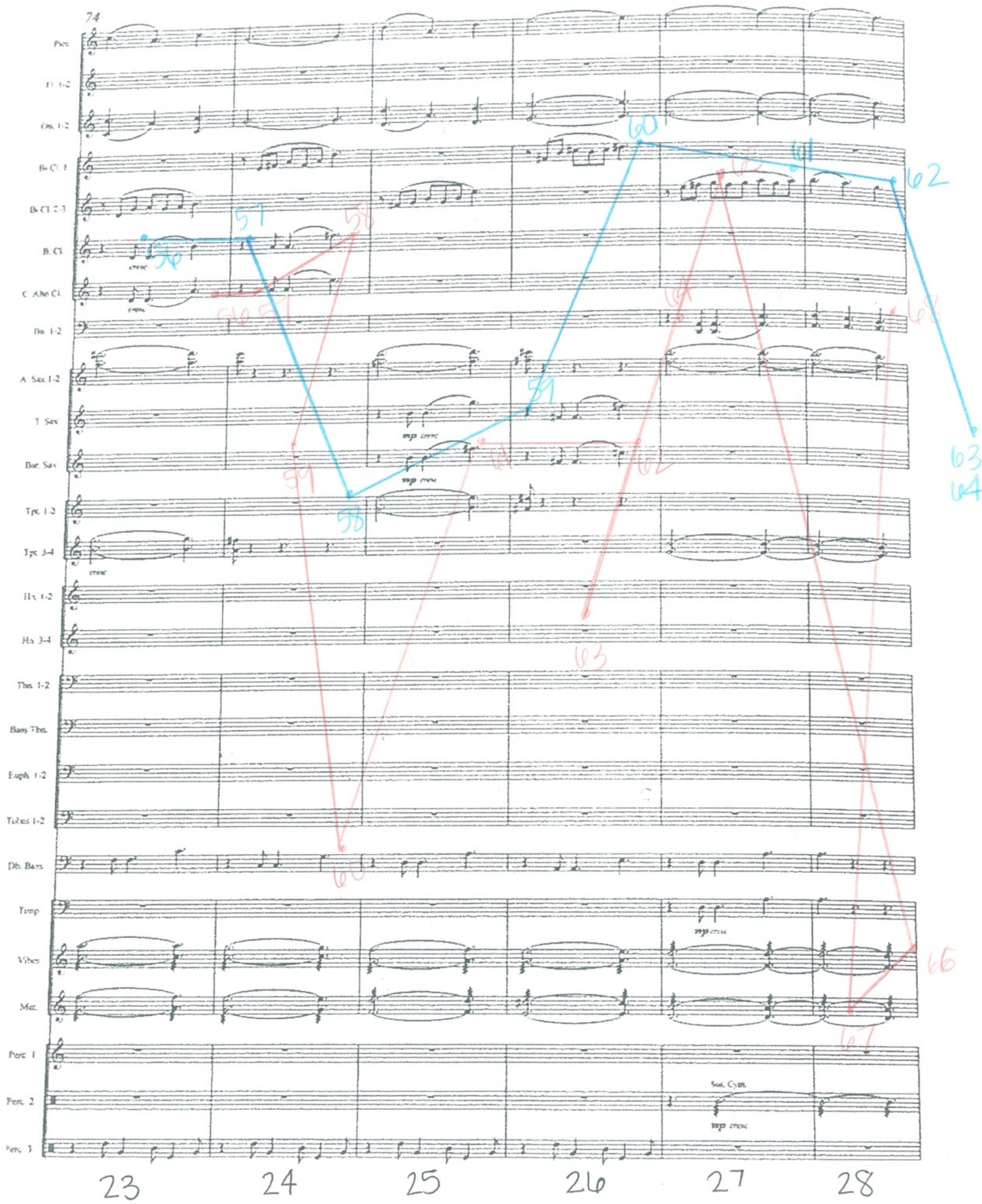
G2
11
54
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax. 1-2
T. Sax.
Bar. Sax.
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
3 4 5 6 7 8 9 10

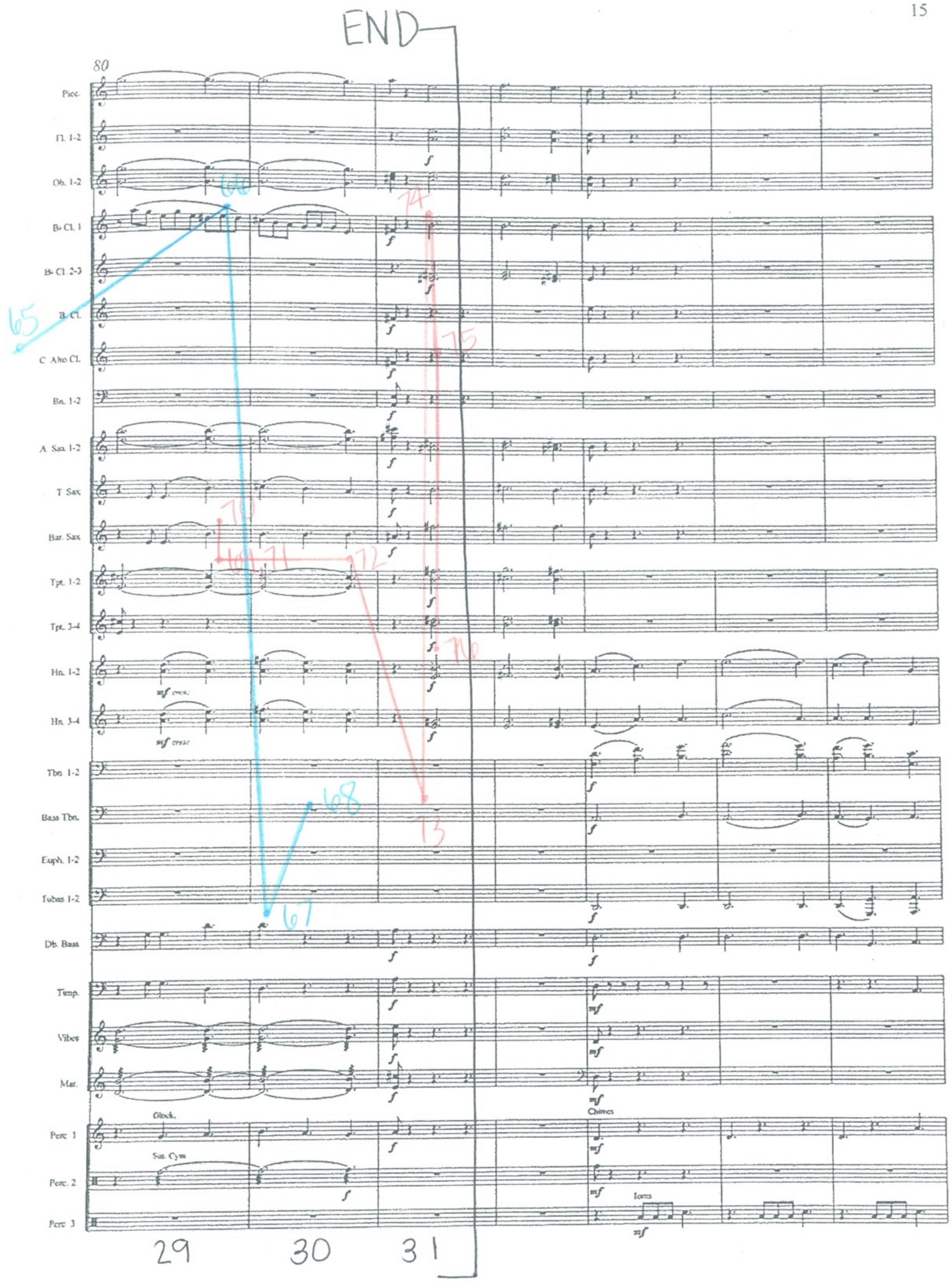
G2


12
62
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Glock.
Perc. 2
Sus. Cym.
Perc. 3
T. Blk.
11
12
13
14
15
16
37,38
39

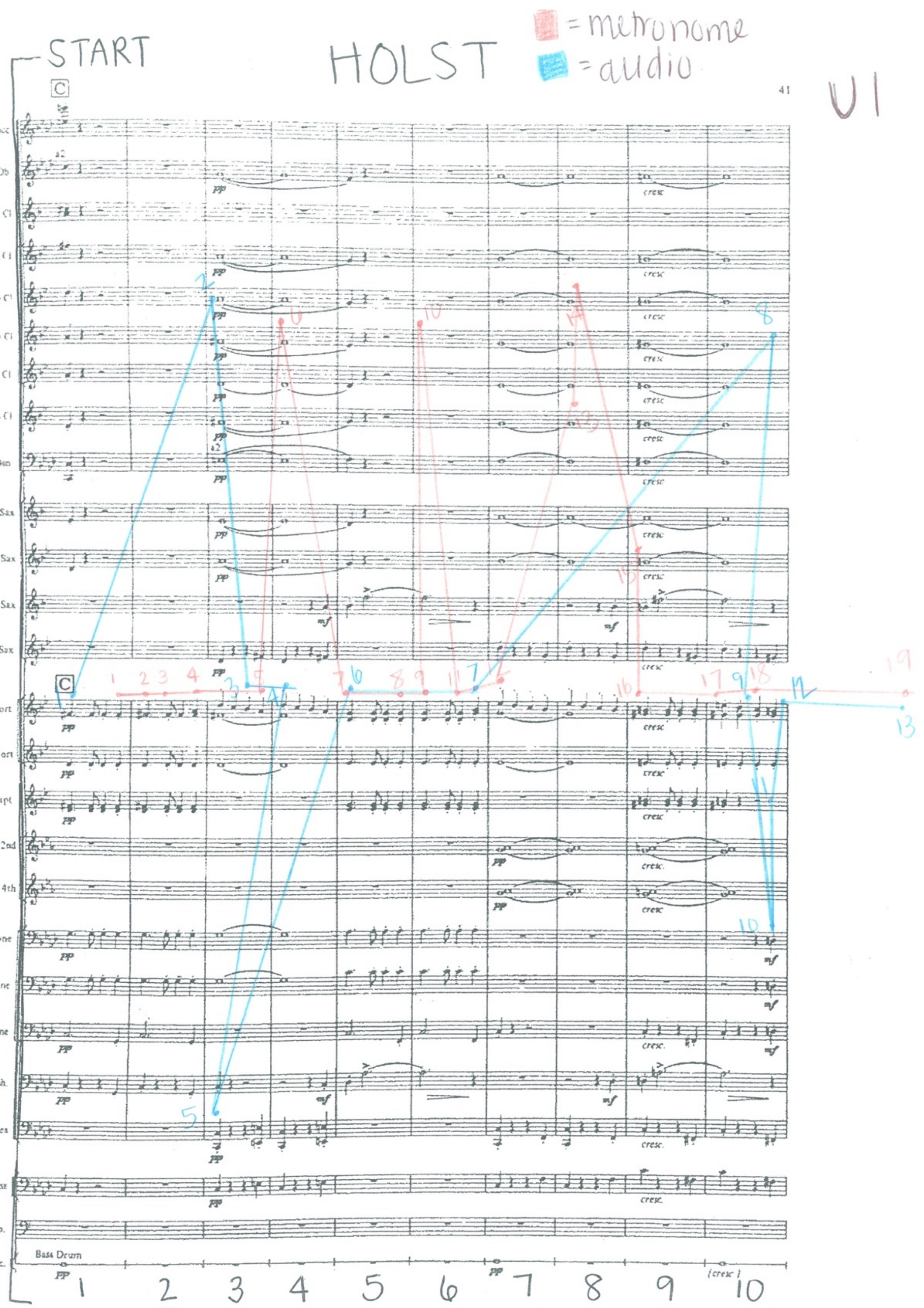

68
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
T. Blk.
17
18
19
20
21
22

G2

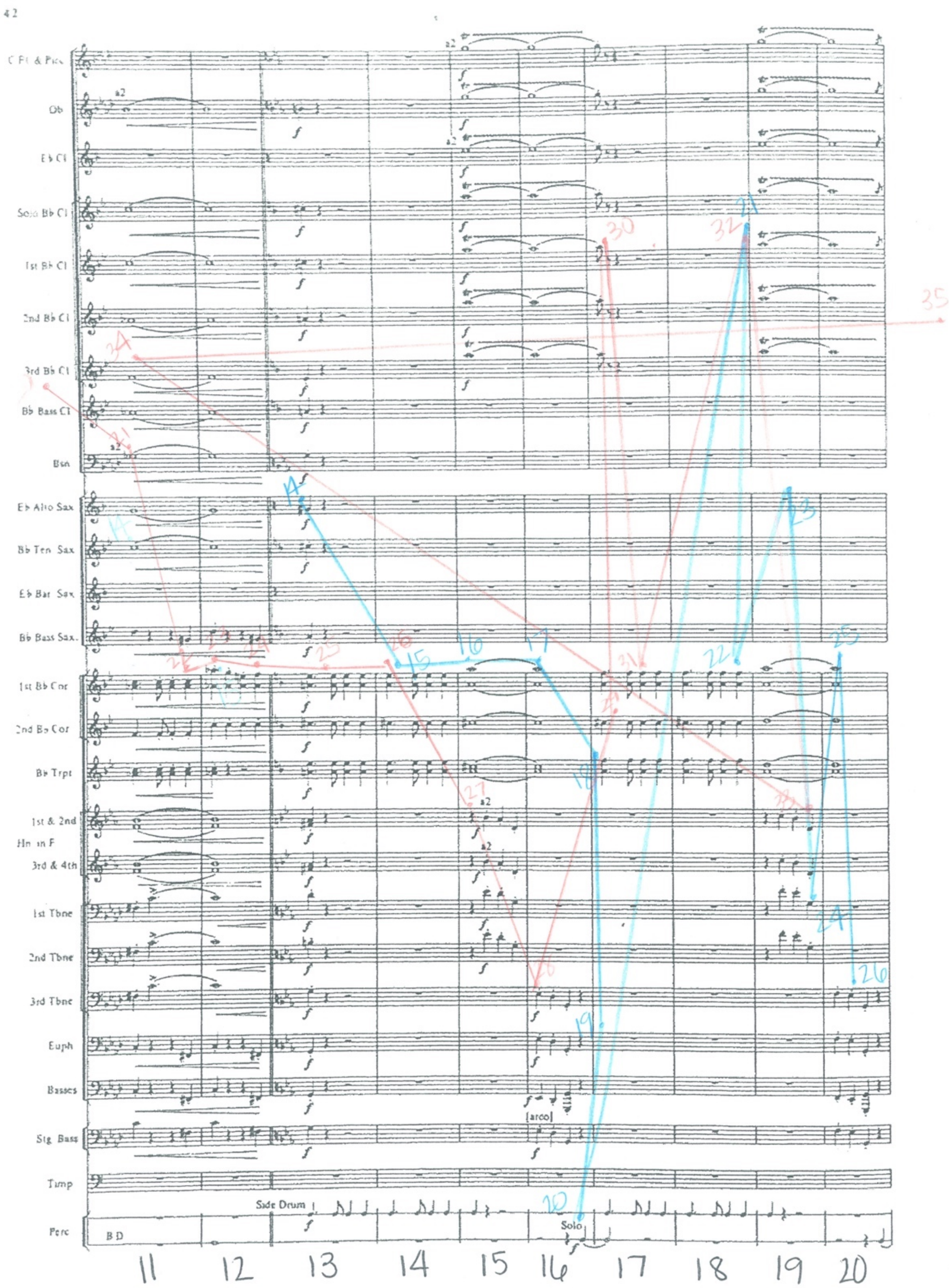

74
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Sus. Cym.
mp cresc.
23
24
25
26
27
28

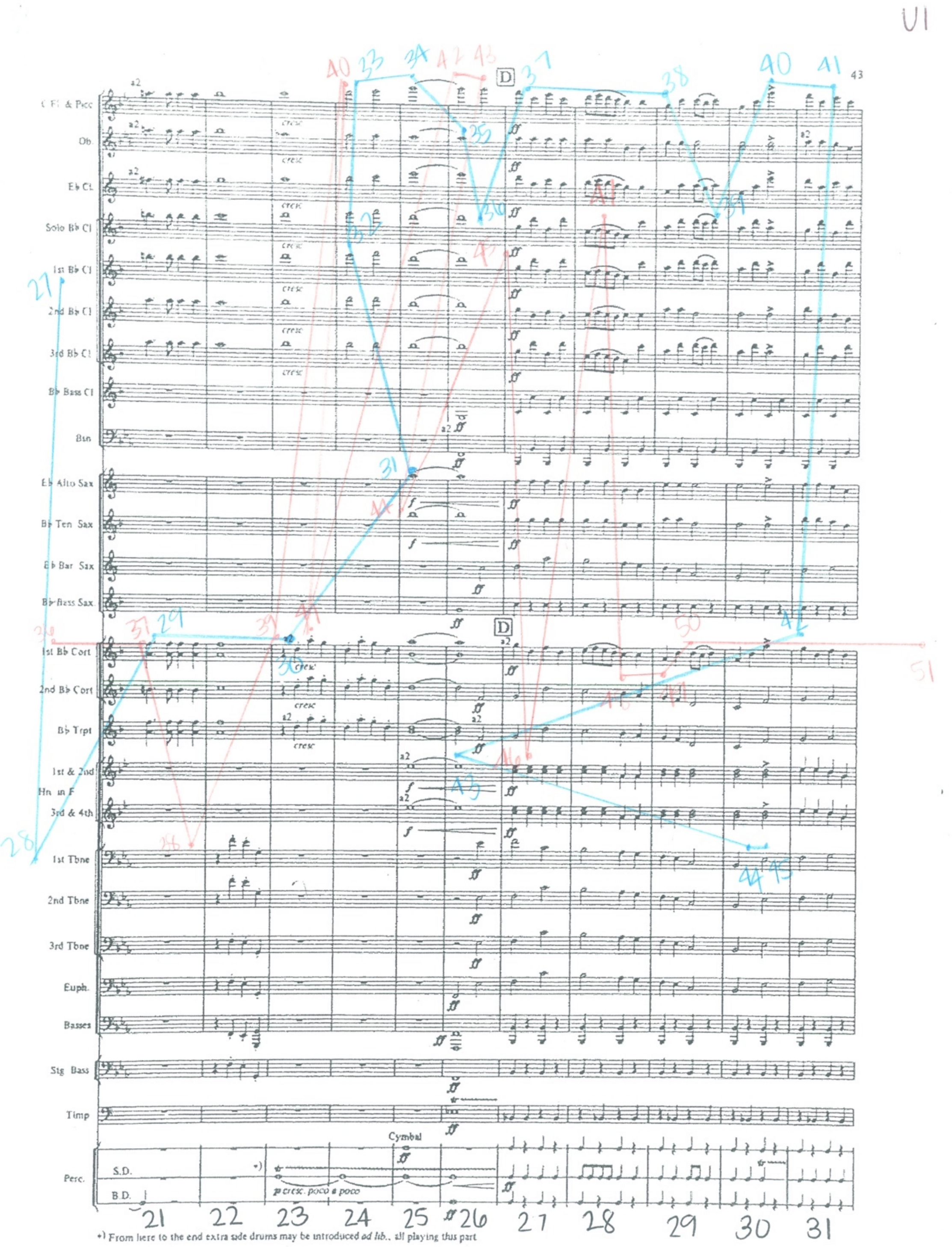


END
80
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C Alto Cl.
Bn. 1-2
A. Sax. 1-2
T. Sax.
Bar. Sax.
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym
Chimes
Toms
mf cresc.
65
66
67
68
69
70
71
72
73
74
75
76
29
30
31


START
HOLST
= metronome
= audio
41
U1
C
C Fl. & Picc
Ob
E♭ Cl
Solo B♭ Cl
1st B♭ Cl
2nd B♭ Cl
3rd B♭ Cl
B♭ Bass Cl
Bsn
E♭ Alto Sax
B♭ Ten. Sax
E♭ Bar. Sax
B♭ Bass Sax
1st B♭ Cort
2nd B♭ Cort
B♭ Tpt
1st & 2nd
Hn. in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph.
Basses
Stg. Bass
Timp.
Perc.
Bass Drum
pp
mf
cresc.
1 2 3 4 5 6 7 8 9 10

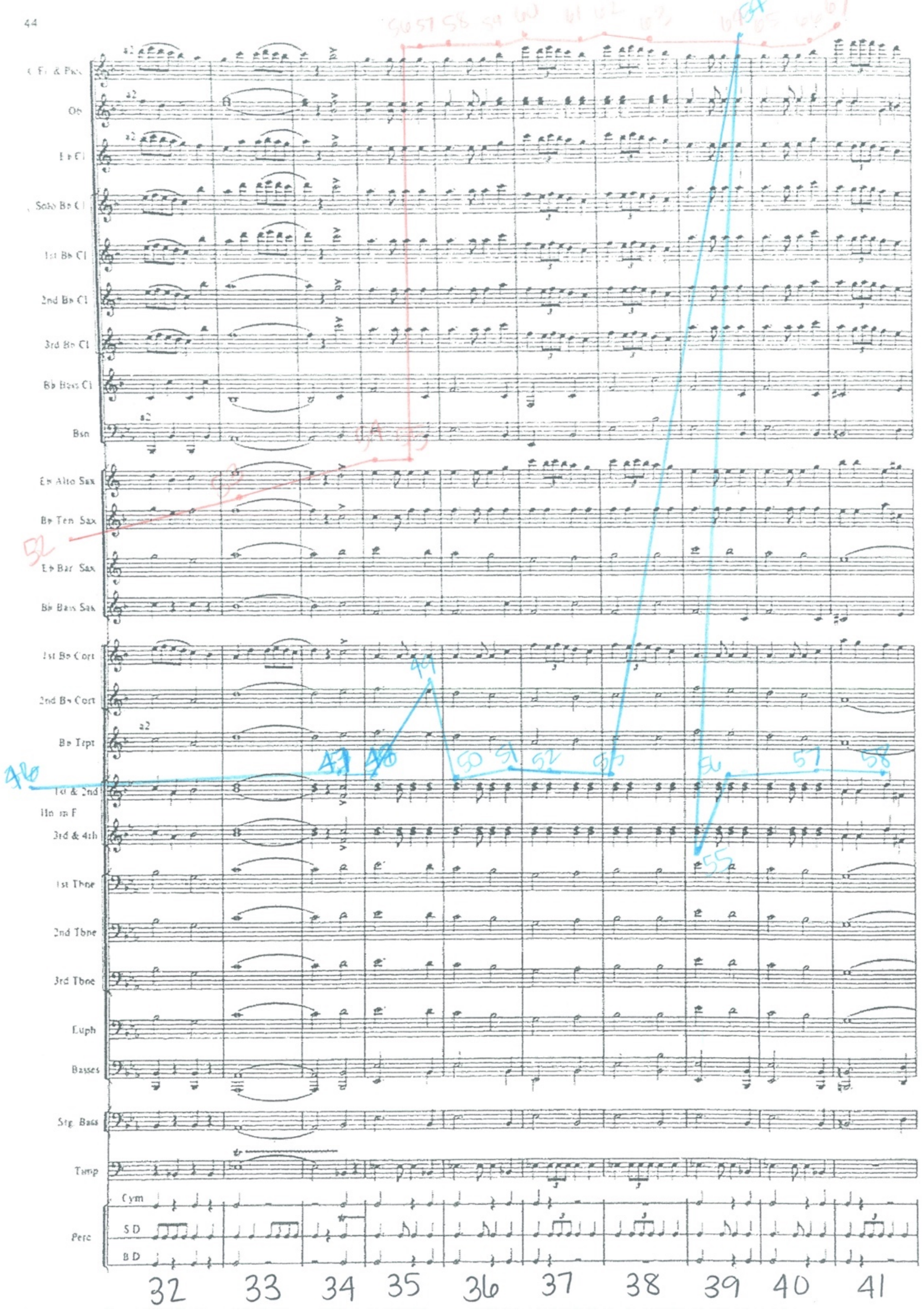
U1


42
C Fl & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax.
1st Bb Cor
2nd Bb Cor
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Side Drum
Perc
B D
[arco]
Solo
11 12 13 14 15 16 17 18 19 20



*) From here to the end extra side drums may be introduced *ad lib.*, all playing this part

U1

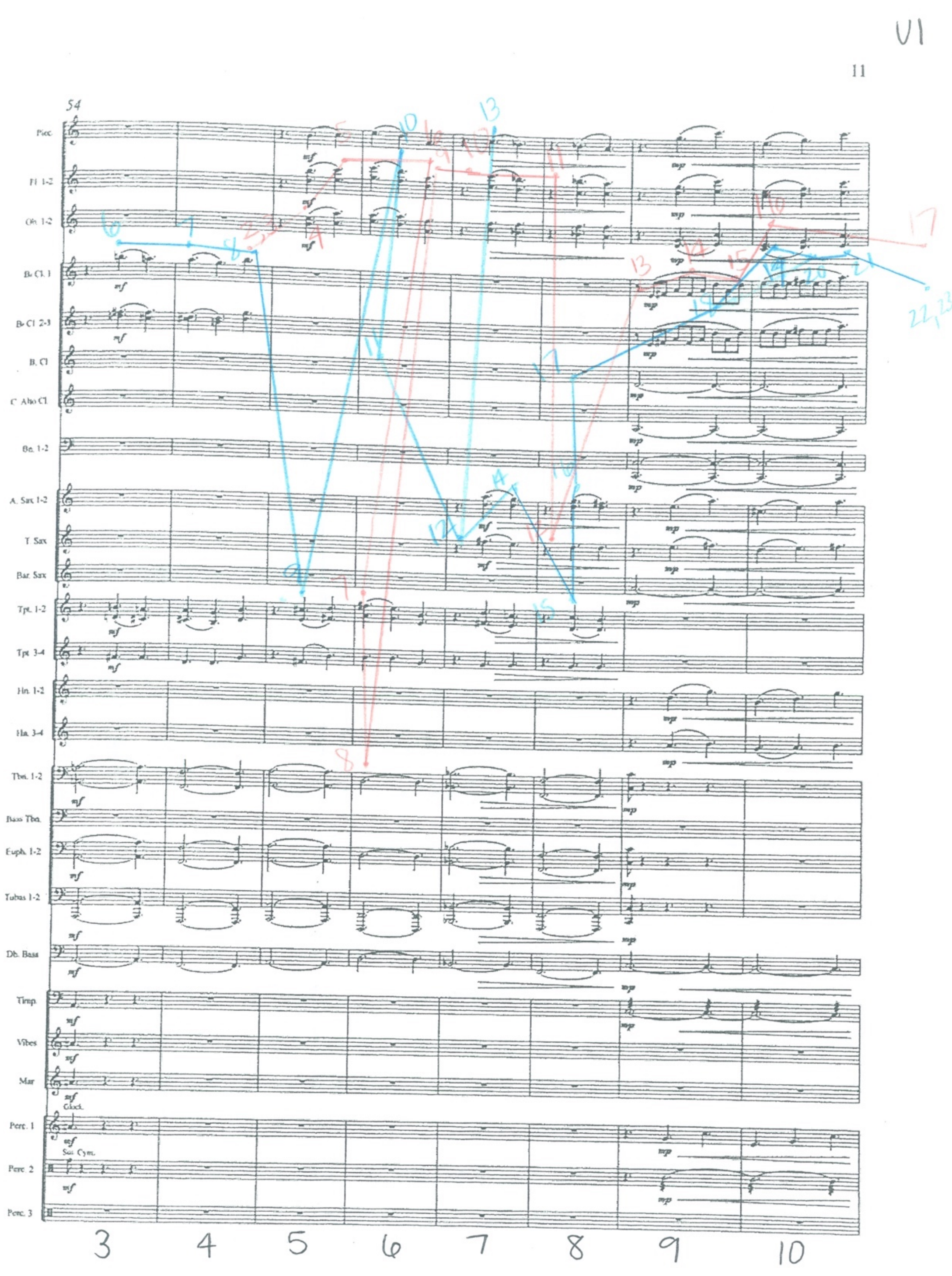


44
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cort
2nd Bb Cort
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg. Bass
Timp
Cym
S D
B D
Perc
32
33
34
35
36
37
38
39
40
41

VI


END
45
C Fl. & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cort
2nd Bb Cort
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph.
Basses
Stg. Bass
Timp
Cym
Perc
S.D.
B.D.
cresc. poco a poco
42
43


= metronome
= audio
EWAZEN
START
U1
48
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc 1
Perc 2
Perc 3
Toms
Glock.
Sus. Cym.
1
2

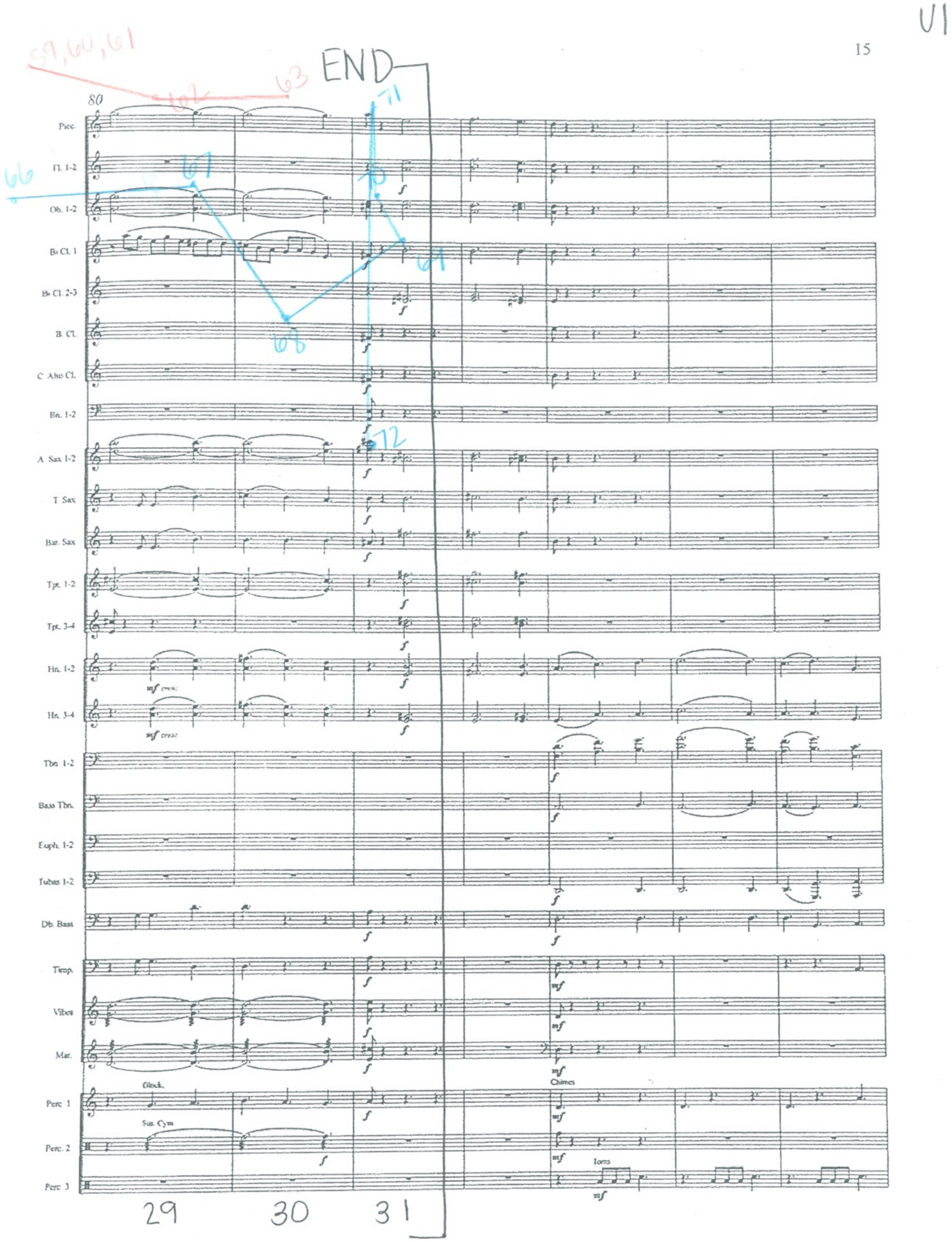

V1
11
54
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Glock.
Perc. 1
Sus. Cym.
Perc. 2
Perc. 3
3
4
5
6
7
8
9
10


62
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
T. Blk.
11
12
13
14
15
16


VI
13
68
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
T. Bk.
mp
cresc
17
18
19
20
21
22

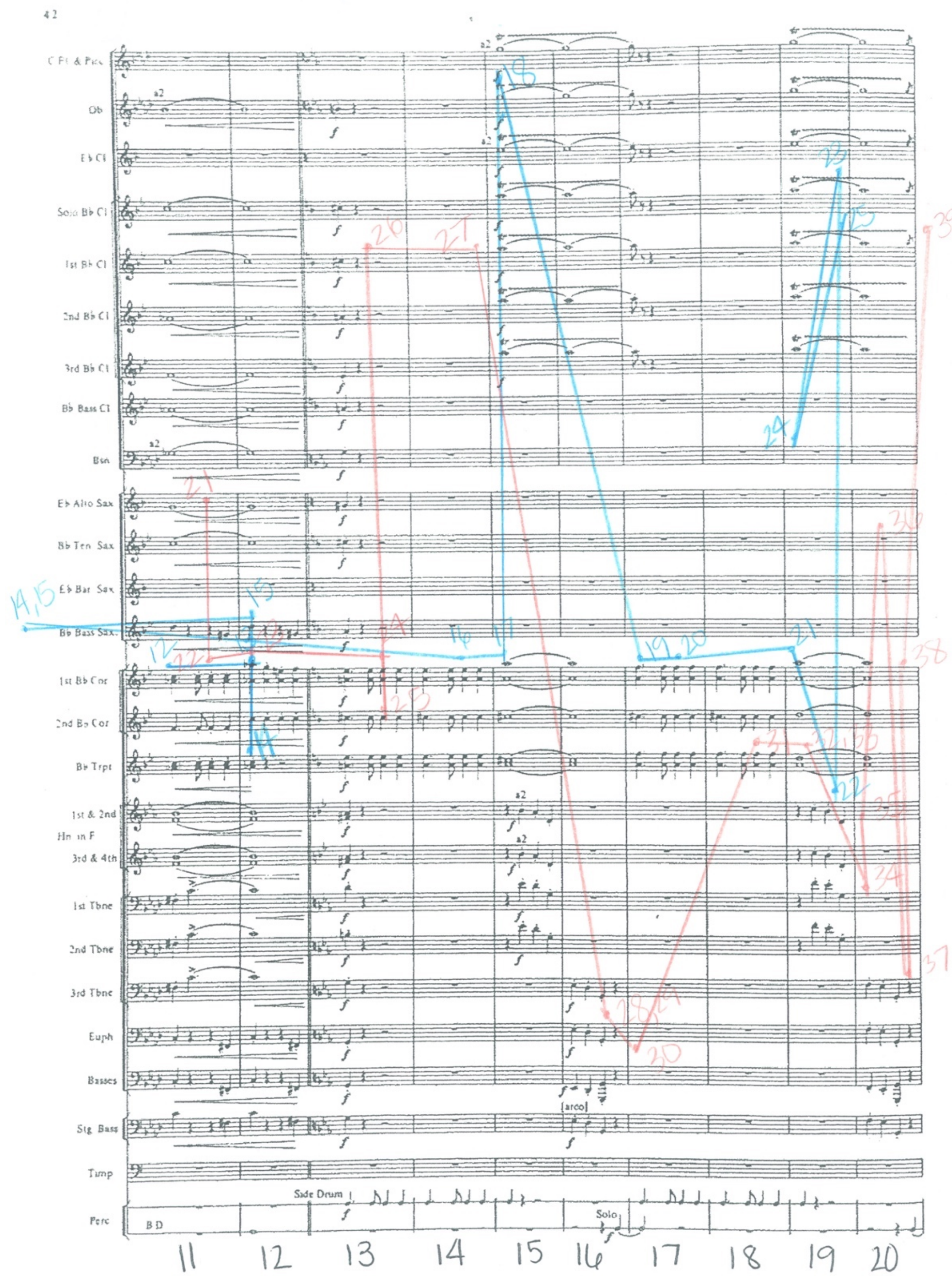
U1

74
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
cresc.
mp cresc.
Sus. Cym.
23
24
25
26
27
28

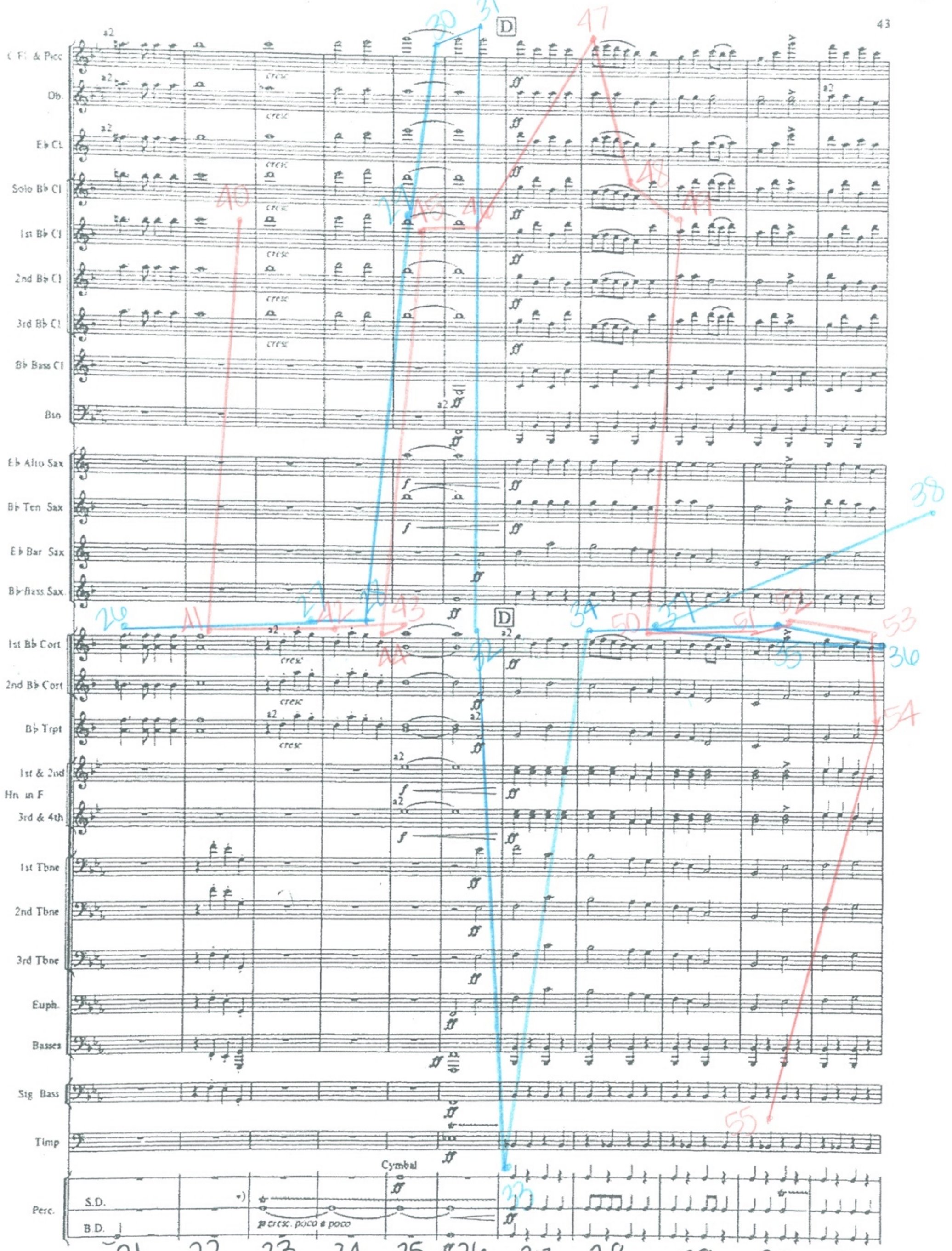

59,60,61
62
63
END
71
66
67
70
69
68
72
80
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax. 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
mf cresc.
Glock.
Sus. Cym.
Chimes
Toms
29
30
31


START
HOLST
= metronome
= audio
U2
41
C
C Fl. & Picc
Ob.
E♭ Cl.
Solo B♭ Cl.
1st B♭ Cl.
2nd B♭ Cl.
3rd B♭ Cl.
B♭ Bass Cl.
Bsn.
E♭ Alto Sax.
B♭ Ten. Sax.
E♭ Bar. Sax.
B♭ Bass Sax.
1st B♭ Cort.
2nd B♭ Cort.
B♭ Tpt.
1st & 2nd
Hn. in F
3rd & 4th
1st Tbne.
2nd Tbne.
3rd Tbne.
Euph.
Basses
Stg. Bass
Timp.
Perc.
Bass Drum
pp
mf
cresc.
1 2 3 4 5 6 7 8 9 10

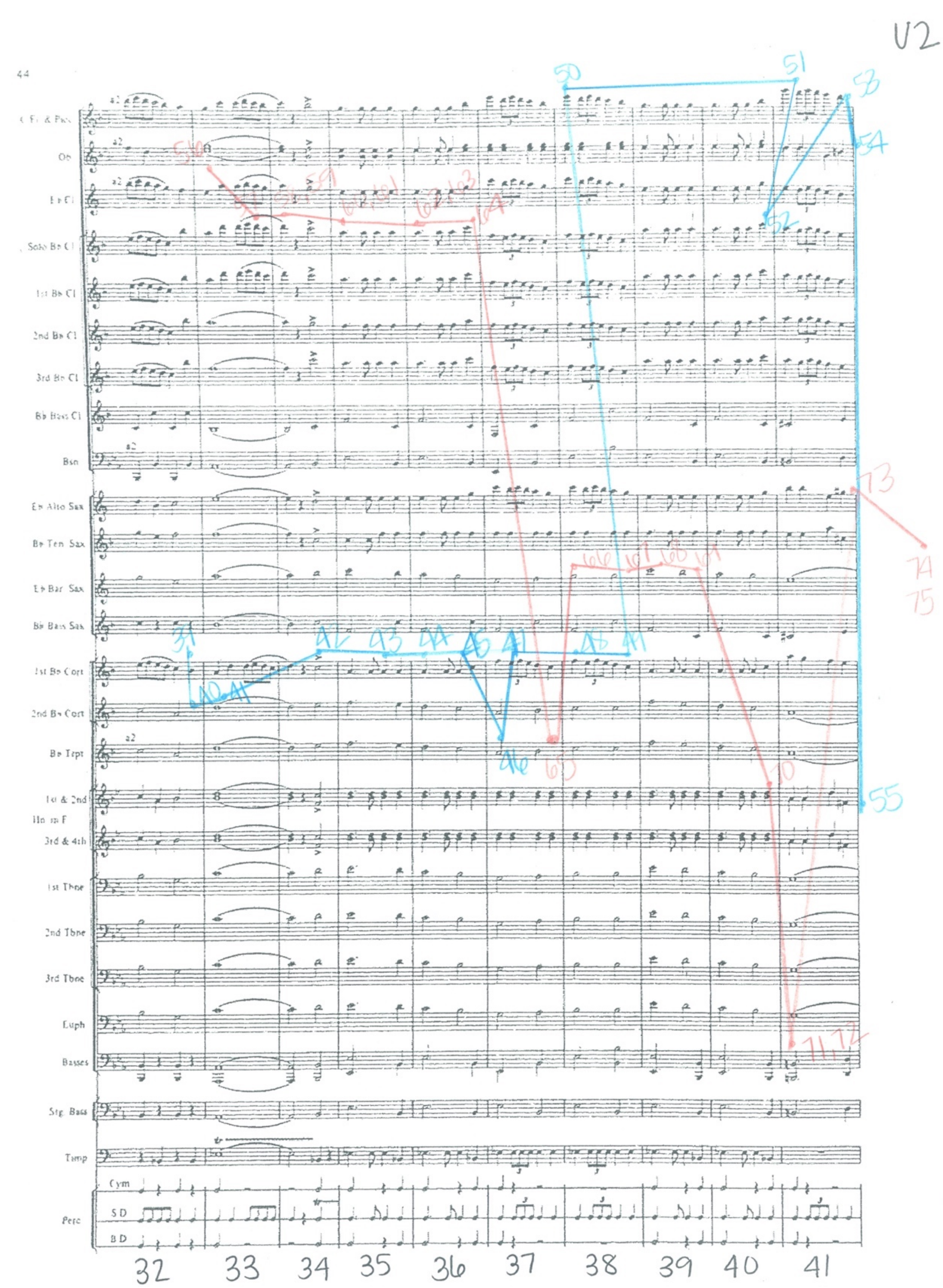
U2


42
Ob
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cor
2nd Bb Cor
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Perc
Side Drum
Solo
BD
[arco]
11 12 13 14 15 16 17 18 19 20

U2



*) From here to the end extra side drums may be introduced *ad lib.*, all playing this part

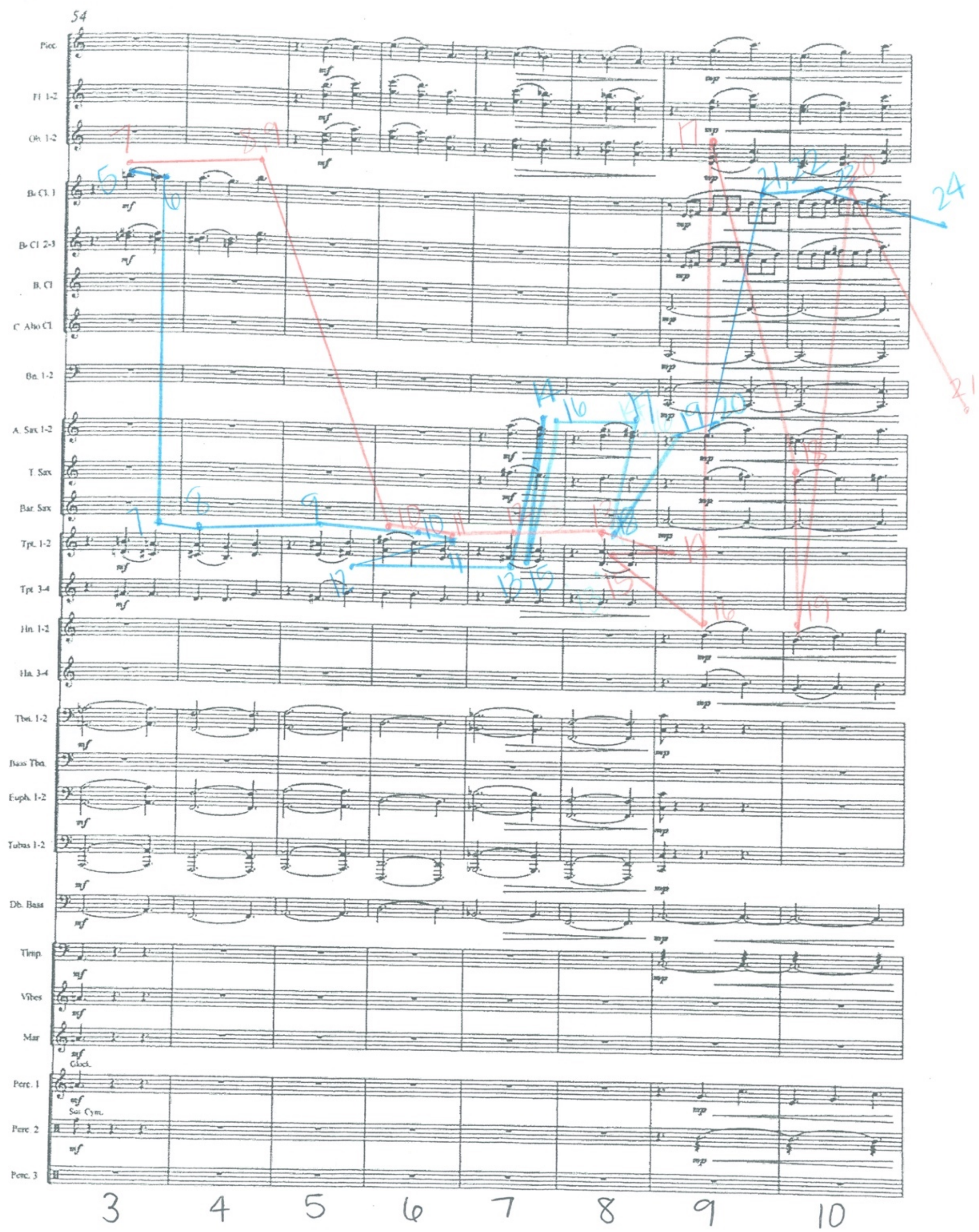

V2
44
C Fl & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cort
2nd Bb Cort
Bb Tpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph
Basses
Stg Bass
Timp
Cym
SD
BD
Perc
32
33
34
35
36
37
38
39
40
41

U2

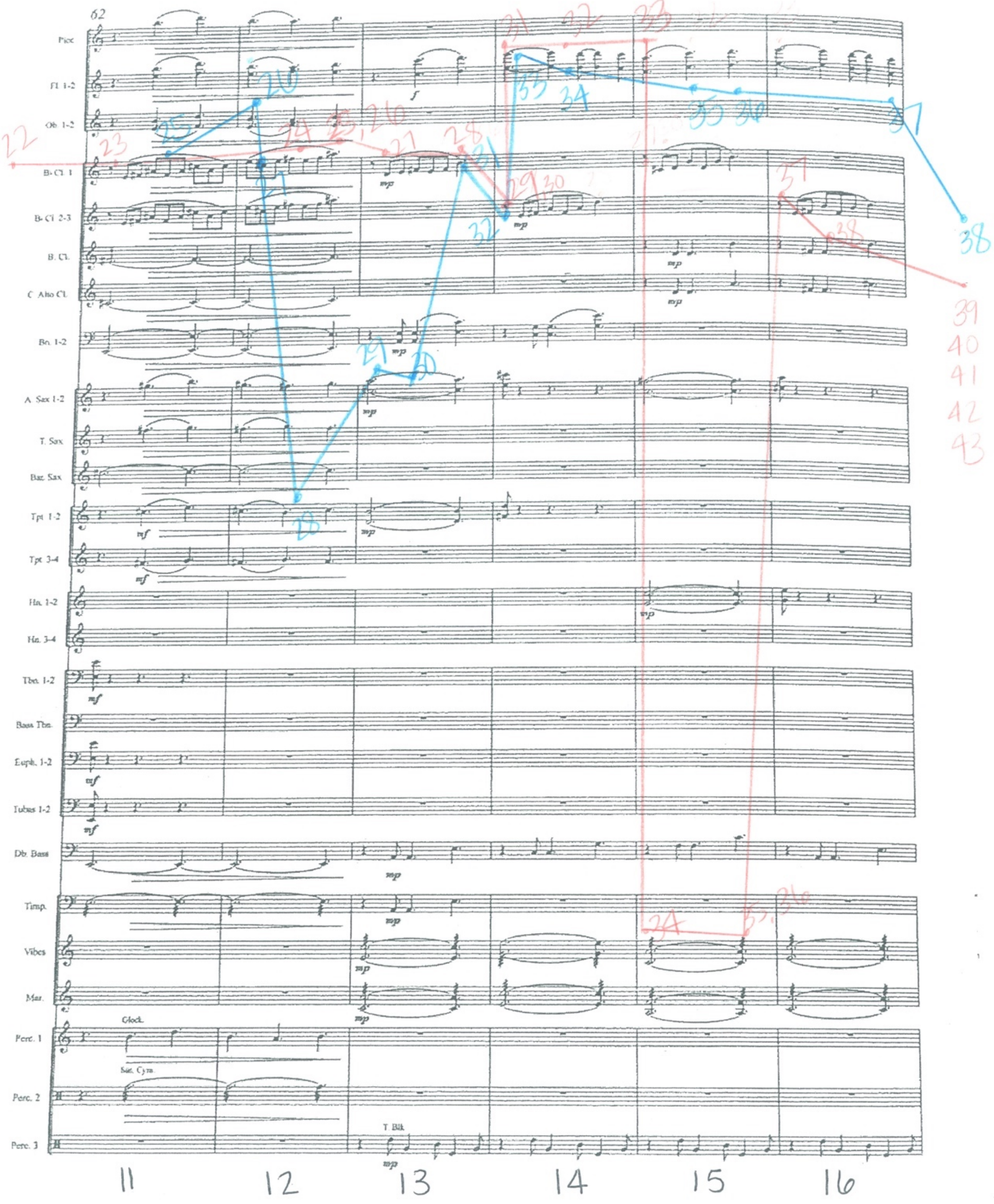

END
45
C Fl. & Picc
Ob
Eb Cl
Solo Bb Cl
1st Bb Cl
2nd Bb Cl
3rd Bb Cl
Bb Bass Cl
Bsn
Eb Alto Sax
Bb Ten Sax
Eb Bar Sax
Bb Bass Sax
1st Bb Cort
2nd Bb Cort
Bb Trpt
1st & 2nd
Hn in F
3rd & 4th
1st Tbne
2nd Tbne
3rd Tbne
Euph.
Basses
Stg. Bass
Timp
Cym
S.D.
Perc
B.D.
cresc. poco a poco
42
43


= metronome
= audio
EWAZEN
START
U2
10
48
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
Toms
1
2

U2

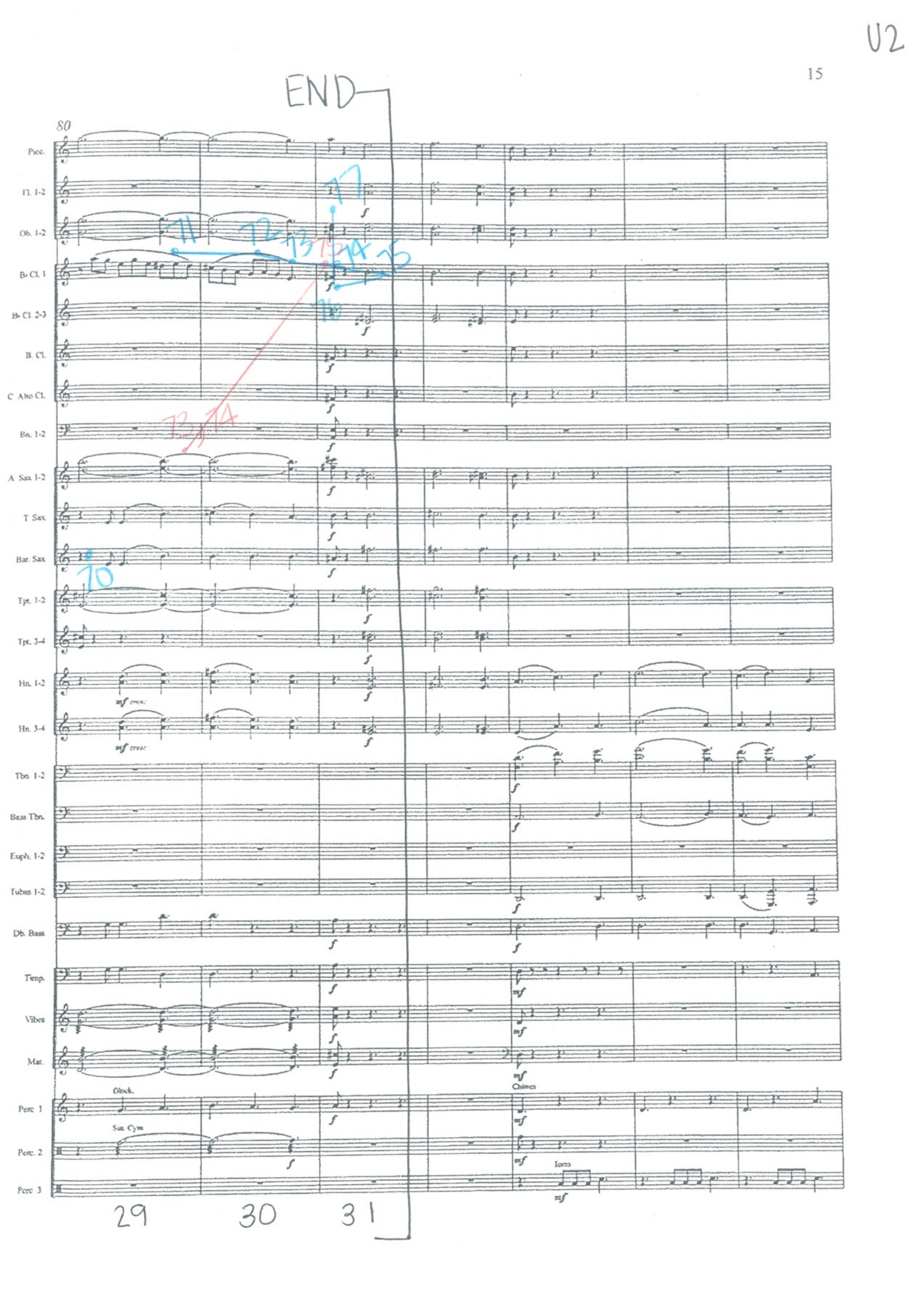

54
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
3
4
5
6
7
8
9
10

U2


62
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
T. Blk.
11
12
13
14
15
16


U2
13
68
Picc
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
T. Blk.
17
18
19
20
21
22

74
Picc.
Fl. 1-2
Obs. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C. Alto Cl.
Bn. 1-2
A. Sax 1-2
T. Sax
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Sus. Cym.
mp cresc.
23
24
25
26
27
28



U2
15
END
80
Picc.
Fl. 1-2
Ob. 1-2
B♭ Cl. 1
B♭ Cl. 2-3
B. Cl.
C Alto Cl.
Bn. 1-2
A. Sax. 1-2
T. Sax.
Bar. Sax
Tpt. 1-2
Tpt. 3-4
Hn. 1-2
Hn. 3-4
Tbn. 1-2
Bass Tbn.
Euph. 1-2
Tubas 1-2
Db. Bass
Timp.
Vibes
Mar.
Perc. 1
Perc. 2
Perc. 3
Glock.
Sus. Cym.
Chimes
Toms
29
30
31

APPENDIX B: EXPERIMENT 2 – VIDEO CLIP SCREENSHOTS

Juggling

Baseball


Ballet


Clarinet 1


Clarinet 2


Saxophone 1


Saxophone 2


Flute 1


Flute 2

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